WRRC
Bulletin 110

PUBLIC WATER SUPPLY QUALITY IN THE ROCK RIVER WATERSHED, Southwest Minnesota

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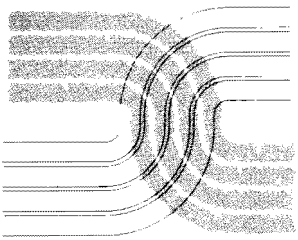

WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
GRADUATE SCHOOL

The work upon which this publication is based was supported in part by funds provided by the U.S. Department of the Interior as authorized under the Water Research and Development Act of 1978. P.L. 95-467.

October 1982

FIGURES

TABLES

ACKNOWLEDGEMENTS

Without the assistance of the following individuals this project would not have been possible.

Adrain - Leo J. Hensen, Water Superintendent

Leota - Frank Gunnink, Water Superintendent

Edgerton - Everett Nagelhorse, City Manager
Leroy Kreun
Arlo Kreun
Bill Vander Brey

Luverne - Vernon Estes, Water Superintendent
Del Domagele, Water Superintendent
Barry Bailey
Marvin Connerman

Hardwick - Emmett Fodness
Eugene Cragoe

In addition the assistance of E.L. Kuehnast, DNR-State Climatologist is acknowledged.

Jack Sahl, Student Assistant, performed some chemical analyses in 1978-1979.

This study was conducted under the auspices of the Environmental Health Research and Training Center, School of Public Health, University of Minnesota, Minneapolis, MN 55455

FOREWORD

This bulletin is published in furtherance of the purposes of the Federal Water Research and Development Act of 1978, P.L. 95-467. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the field of water and resources which affect water. The Act is promoting a more adequate national program of water resources research by furnishing financial assistance to non-Federal research.

The Act provides for establishment of Water Resources Research Centers at Universities throughout the Nation. On September 1, 1964, a Water Resources Research Center was established (under the Water Resources Research Act of 1964, P.L. 88-379) in the Graduate School as an Interdisciplinary component of the University of Minnesota. The Center has the responsibility for unifying and stimulating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This Bulletin is number 110 in a series of publications designed to present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center.

This Bulletin is related to:

OWRT Project No.: A-038-Minn

Project Title: Water Quality Studies: Southwestern Minnesota

Principal Investigator: Conrad P. Straub, Professor and Director,*
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University of Minnesota, Minneapolis, MN

Project Began: October 1, 1977 Project Completed: September 30, 1980

FCST, COWRR Research Category: VII-B; 8, 13

Publication Descriptors: Minnesota/Water Quality/Municipal Water Supplies/
Ground Water Quality/Public Health/Surface Water
Quality/Anions

*Stepped down as Director, June 30, 1980

Publication Abstract:

Several municipal water supplies in the Rock River watershed in Southwestern Minnesota were tested on approximately a monthly basis for a little over two-years for the anions nitrate-nitrogen, sulfate, chloride, and bicarbonate alkalinity as calcium carbonate, and for total dissolved solids, conductivity, and pH. Anions were selected for analysis because it was felt that they were better descriptors of the effect of land use practices on ground water quality. The ratios of the various anions sulfate/nitrate-nitrogen, chloride/nitrate-nitrogen, sulfate/chloride, and bicarbonate alkalinity as calcium carbonate/sulfate served to identify changes in water qaulity not associated with dilution.

Findings indicated seasonal changes in water quality not necessarily reflected in changes in the ratios, generally increasing concentrations of nitrate-nitrogen in many instances, exceeding permissible concentrations specified in the Interim Primary Drinking Water Standards, and high dissolved solids concentrations generally exceeding recommended levels specified in the Secondary Drinking Water Standards.

Ground water concentrations were compared with surface water samples from the several streams, springs, and lakes in the area. Some relations to land use practice on ground water quality and precipitation were indicated.

The data have been utilized to call attention to deficiencies in water quality to the consumers of the waters in the communities concerned.

1.0. INTRODUCTION

1.1. Background

An earlier study[1] indicated that municipal water supplies in southwest Minnesota showed the greatest departure from accepted water quality norms.[2-4] The earlier study also showed the lack of continuous data available on water quality. The current study provides a continuous record extending over a two-year period on specific anionic and other constituents in five rural municipal water supply systems and the effects of land use practices on water quality. The material presented is a condensation of a more detailed report.[5]

1.2. Study Area

The study area selected (shown in Fig. 1) was located in the Rock River basin, and included two communities in Nobles County (Adrian-1970 population 1378 and Leota-1970 population 125), one community in Pipestone County (Edgerton-1970 population 1119), and two communities and one individual rural farm supply in Rock County (Hardwick-1970 population 273 and Luverne-1970 population 4703). The rural farm supply was located near Hardwick. The Rock River was sampled at three locations: in Edgerton, near Hardwick, and in Luverne; Kanaranzi Creek was sampled at two locations in the Adrian area. Two spring samples located in the Adrian area were sampled also as was a tile field drain near Leota. Surface water samples were collected from ponds located near the south well field in Luverne.

Ground water served as the source of supply for all communities studied; each served by a single well or several wells. For example, Leota and Hardwick were each served by a single well, Adrian and Edgerton by four wells each, and Luverne by 14 wells -- seven in each of two well fields.

1.2.1. Ground Water Quality

Generalized information on ground water sources in the Rock River Basin was obtained from Hydrogeological Investigations Atlas HA-555.[6] The report states: "Glacial outwash sand and gravel is an important surficial aquifer along the Rock River and several major creeks and generally ranges in thickness from 0 to 40 feet." All wells sampled were shallow, and presumably in the glacial outwash sand and gravel, with the exception of the well at Hardwick which had a depth of 410 ft. The Sioux quartzite aquifer is tapped by this well. The report goes on: "Quality of water in glacial aqifers is affected by deposit, depth, surficial drainage, and location. Water in bedrock aquifers contains chemical properties similar to those in water from overlying glacial aquifers and is affected by drainage from bedrock highs." with . . . "glacial deposits and permeable bedrock forming a single interconnected hydrologic system which moves vertically and horizontally in response to differences in hydraulic potential."

1.2.2. Rainfall

Shallow ground water aquifers are dependent, in many instances, on the infiltration of precipitation and contributions from surface waters. Water quality is also markedly affected by precipitation, surface cover of the land, and the utilization of the land in question--farming, animal production, recreation, and industry.

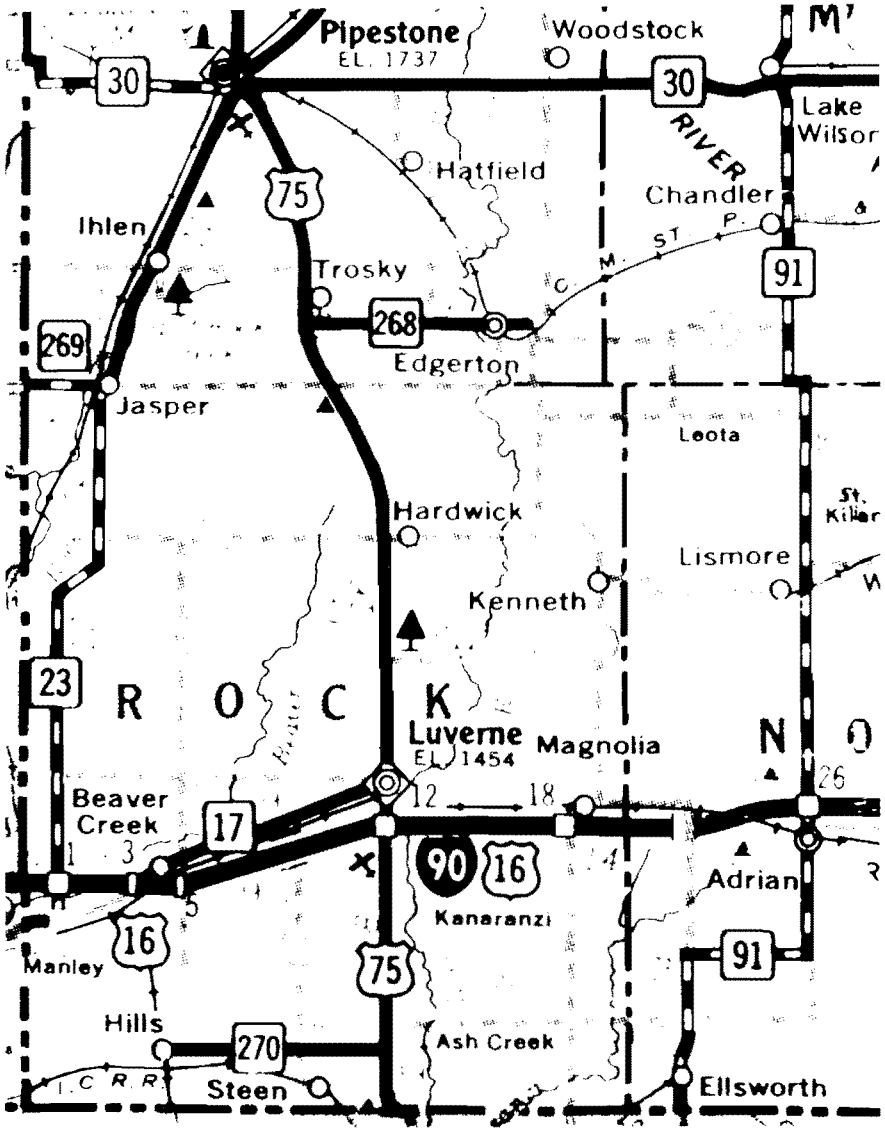


Fig. 1. Map showing study area

To assess the possible effect of rainfall on ground water quality, precipitation data were obtained from the State Climatologist[7] and that recorded at the Luverne Wastewater Treatment Plant.[8] It is extremely difficult to compare rainfall data which consists primarily of localized scattered showers over such a relatively large area to specific ground water situations monitored by our sampling operations. Increased rainfall and infiltration will carry oxidized or mineralized nitrogen forms (primarily nitrate-nitrogen) into the ground water; limited precipitation and infiltration will keep the mineralized nitrate and other anions from migrating from the upper soil horizons to lower formations. Thus, higher concentrations of these anions will be available for plant uptake. During the drought of 1976 higher concentrations of nitrates were reported in feed grains. Animals consuming these feed-stuffs were exposed to higher intakes of nitrate-nitrogen and reports indicated problems with young, weaned animals consuming high nitrate feedstuffs and water.

1.3. Study Objectives

Based upon data from our earlier study[1] five communities, served by single or multiple wells from somewhat similar aquifers in the Rock River basin, were selected for study. Analyses included chlorides, sulfates, and nitrate-nitrogen, conductivity, and total dissolved solids; bicarbonate alkalinity as calcium carbonate and pH were added about midway through the study. The anions selected -- initially chlorides, sulfates, and nitrate-nitrogen and later bicarbonate alkalinity -- move through the soil more readily and, therefore, should provide more specific information regarding changes in water quality as affected by land use practices, surficial contamination, and precipitation. Total dissolved solids, conductivity, and pH would provide information characterizing ground water infiltration from runoff or input from flood and baseflow from surface waters.

1.4. Sampling

Twenty-seven samples each were collected from most of the sampling points during the period April 5, 1978 through May 21, 1980. Lesser numbers of samples were collected from surface sources during winter when frozen over or when there was a lack of water. Samples were collected by two of us (CPS and RDS) with the help, in most cases, of the local water superintendent or one of his assistants. Samples were collected in two-liter, glass-stoppered bottles, which had been carefully washed and processed to minimize contamination, and stored on ice, as necessary. Samples were returned to the laboratory within 24 hours after collection and stored under refrigeration until analyzed. Samples were collected from the distribution system in each community and from each well where more than one well contributed to the source of supply. In addition to the routine sampling outlined above, two series of samples were collected over 24-hour periods from Well 2 at Adrian to determine changes in nitrate-nitrogen as a result of continuous pumping. On two occasions, samples subject to additional treatment by reverse osmosis were collected in a restaurant in Adrian and analyzed for the parameters indicated earlier.

A total of 1077 samples were collected for analysis.

1.5. Analytical Methods

With the exception of the analysis of nitrate-nitrogen, all procedures followed those given in Standard Methods.[9] With the wide range of nitrate-nitrogen values observed in the samples collected, the brucine method described in Standard Methods did not give consistent results and had to be modified. Increased concentrations of brucine, over those specified in Standard Methods, yielded more consistent and accurate results over the range of values observed. The Hach conductivity meter was used to measure conductivity.

All results are reported to two siginificant figures.

1.6. Basis for the Analytical Approach

As indicated earlier, anions, specifically chloride, sulfate, and nitrate-nitrogen, would serve as good indicators of changes in water quality, particularly if these anions were contributed through surficial contaminants indicative of land use practices. The chlorides and sulfates would also represent contributions resulting from contact of infiltrating waters with soil minerals or geologic formations. Anionic ratios would not be affected by dilution or concentration.

One of the anions measured, nitrate-nitrogen, is health related and maximum concentration limits have been prescribed in the Interim Primary Drinking Water Standards.[4] To minimize health effects associated with methemoglobinemia in infants this limit has been set at 10 mg nitrate-nitrogen/L. Limits for sulfate, chlorides, and total dissolved solids are currently included in the secondary regulations--those concerned with the aesthetic quality of water.[10] Although indigenous populations readily acclimate to high sulfate levels, transient populations can suffer debilitating effects. The limits prescribed for chlorides, sulfates, and total dissolved solids are 250, 250, and 500 mg/L, respectively. Changes in chloride level would result from the used of chloride-containing salts used for de-icing, as well as from animal excreta, septic tank discharges, and fertilizers. Sulfate concentrations would result from soil and bed rock dissolution, surface runoff, etc. Abrupt changes in sulfate levels should be viewed with suspicion. The results are reported for each community.

To assist in identifying changes in the anion concentrations reported, due to factors other than dilution or concentration, anionic ratios have been calculated: sulfate/chloride, sulfate/nitrate-nitrogen, chloride/nitrate-nitrogen, and bicarbonate alkalinity as calcium carbonate/sulfate.

2.0. SUMMARY AND CONCLUSIONS

2.1. Summary

The purpose of the study was to determine the seasonal variability in water quality in individual wells extracting water from similar or different aquifers serving as sources of municipal water supply in rural communities, and to relate these changes in water quality to land use practices.

A total of 1077 routine water samples were collected from 43 sampling

points during the period April 4, 1978 through May 21, 1980. Samples were collected from individual wells serving the communities of Adrian, Edgerton, Hardwick, and Luverne,from distribution systems in Adrian, Leota, Edgerton, and Luverne, from two water treatment plants in Luverne, from an individual rural farm water supply, and from surface waters -- rivers, creeks, springs, and ponds. All waters sampled were in the Rock River Basin.

The samples were analyzed for the anions: sulfate, chloride, and nitrate-nitrogen to measure the role of these potential surficial contaminants on ground water quality. Of particular concern were the nitrate-nitrogen levels since the National Interim Drinking Water Standards limit the concentration to 10 mg nitrate-nitrogen/L. Additional supportive analyses include bicarbonate alkalinity as calcium carbonate, pH, conductivity, and total dissolved solids. The following ratios of anions were also calculated: sulfate/chloride, sulfate/nitrate-nitrogen, chloride/nitrate-nitrogen, and bicarbonate alkalinity as calcium carbonate/sulfate.

2.2. Conclusions

Specific conclusions are included under each water supply. Those presented here are general conclusions applicable to the study.

The results show that a number of samples exceeded the Primary and Secondary standards for nitrate-nitrogen and total dissolved solids, respectively. These results, along with those for chloride and sulfate, are summarized in Table 1.

Differences in water quality were observed in the individual wells serving the municipality indicating seasonal and other variations in ground water quality. Where distribution system waters were a blend of inputs from specific wells these reflected characteristics of the primary source, as well as location of the sample taken in relation to location of wells (see Adrian pumping station distributions system sample as compared with the public school drinking water sample).

The reporting of mean values for a series of samples has no validity in cases of increasing or decreasing concentration and perhaps more reliance can be given to the reporting of median values and ranges observed.

Seasonal variations in water quality reflected land use practices as well as changes associated with precipitation.

The variation in concentrations observed also reflects upon the credance of the U.S. EPA requirement of a single analysis for inorganic constituents in water at intervals of three years. Where there is a variation in concentrations there is a need for more frequent sampling.

In many wells serving these communities, the concentrations of nitrate-nitrogen are increasing, with levels exceeding 10 mg nitrate-nitrogen/L, reflecting land use practices -- agriculture, agri-business, etc. Since practical, economic treatment methods are not available for the removal of anions, this problem of increased nitrate-nitrogen concentrations in small rural communities is particularly significant. If concentrations continue to increase, there will be a need to substitute more satisfactory supplies or to indicate, as was done by one community, that the municipal supply should not be used in the preparation of infant formula, particularly for

Table 1. Number of samples exceeding permissible or recommended values[4, 10]

Location		Permissible Levels NO_3^--N <10 mg/L	Recommended Levels $SO_4^=$ <250 mg/L	CL^- <250 mg/L	Total Dis. Solids <500 mg/L
Adrian -	Well 1		8/27		27/27
	Well 2	17/27			27/27
	Well 3	16/27			27/27
	Well 4	19/27	1/27		27/27
	Power Plant DS	1/27			27/27
	Public School DS	9/25			27/27
Leota -	DS	5/27			26/27
Edgerton -	Well 1	16/27			21/27
	Well 2	2/25			24/25
	Well 10	19/27			1/27
	Shop Well	23/27			27/27
	DS	17/27			12/27
Hardwick -	DS				
Luverne -	So. Field				
	Well 7				26/27
	Well 9				25/26
	Well 10	9/24			21/24
	Well 11				26/26
	Well 12	13/25			23/25
	Well 12B				14/14
	Well 13	1/25			24/25
	WW - 2				24/24
	No. Field				
	Well 2				19/25
	Well 3				15/27
	Well 5A				7/27
	Well 6A				11/23
	Well 19				11/26
	Well 20A				11/27
	Well 21				16/22
	WW - 1				4/24
	DS				20/26
Rural Farm	Well	26/27	10/27	2/27	27/27

infants under three months of age. Furthermore, water quality becomes more important as the use of home dialysis equipment becomes more widespread.

Individual farm supply, showed higher concentrations of all parameters measured. The individual owning the supply, recognizing the deterioration in water supply and also its effect on his farm animals, joined a Rural Water District.

The study points out the need for more frequent monitoring and surveillance of rural municipal water supply systems and the need for improvement of water quality in these systems.

3.0. ADRIAN

3.1. Introduction

The four wells serving the Village of Adrian are located as shown in Fig. 2. Well 1 is located north of the Power Plant, Well 2 north of the railroad tracks and of the fertilizer receiving and dispensing facility and south of a general feed grain supply facility, Well 3 south of Franklin Street near the municipal swimming pool, and Well 4 north of Rice Street. The latter two wells are located north of the concrete pipe plant and are in a recreational area.

Information contained in Public Water Supply Data[11] regarding water supply facilities in Adrian follows: Population (1970) 1338, the supply is municipally owned and serves 400 service connections, average daily consumption is 110,000 gal (82.2 gal/capita-day or 275 gal/service connection-day), with 150,000 gal elevated storage. Well 1 is a dug well, 14 ft in diameter, 56 ft deep, installed in 1948, and equipped with a vertical turbine pump of 125 gpm capacity; Well 2 is a dug well, 14 ft in diameter, 43 ft deep, installed in 1948, and equipped with a vertical turbine pump of 90 gpm capacity; Well 3 is a drilled well, 32 ft deep, installed in 1956, and equipped with a vertical turbine pump of 115 gpm capacity; and Well 4 is a drilled well, 38 ft deep, and equipped with a vertical turbine pump of 115 gpm. The treatment provided consists of the addition of hydrofluosilicic acid to increase the fluoride content of the water. These wells were sampled approximately monthly along with two locations on the distributions system -- the cold water tap in the power plant machine shop and a cold water tap in the kitchen of the public school. On two occasions when access to the school was limited, samples were taken from a drinking fountain in the Education Office building located next door to the school. When high nitrate-nitrogen levels in Well 2 precluded its use as a source of supply, use of the well was discontinued, but we continued sampling throughout the remainder of the study period.

3.2 Results

3.2.1. Well 1

The results obtained are shown in Fig. 3 and may be summarized as follows: sulfate levels ranged from 180 to 270 mg/L, with mean and median values of 240 and 230 mg/L, respectively; chloride levels ranged from 20 to 51 mg/L, with mean and median values of 29 and 28 mg/L, respectively; nitrate-nitrogen levels ranged from<0.1 to 8.2, mg/L, with mean and median values of 1.8 and 1.2 mg/L, respectively; bicarbonate alkalinity ranged from 220 to

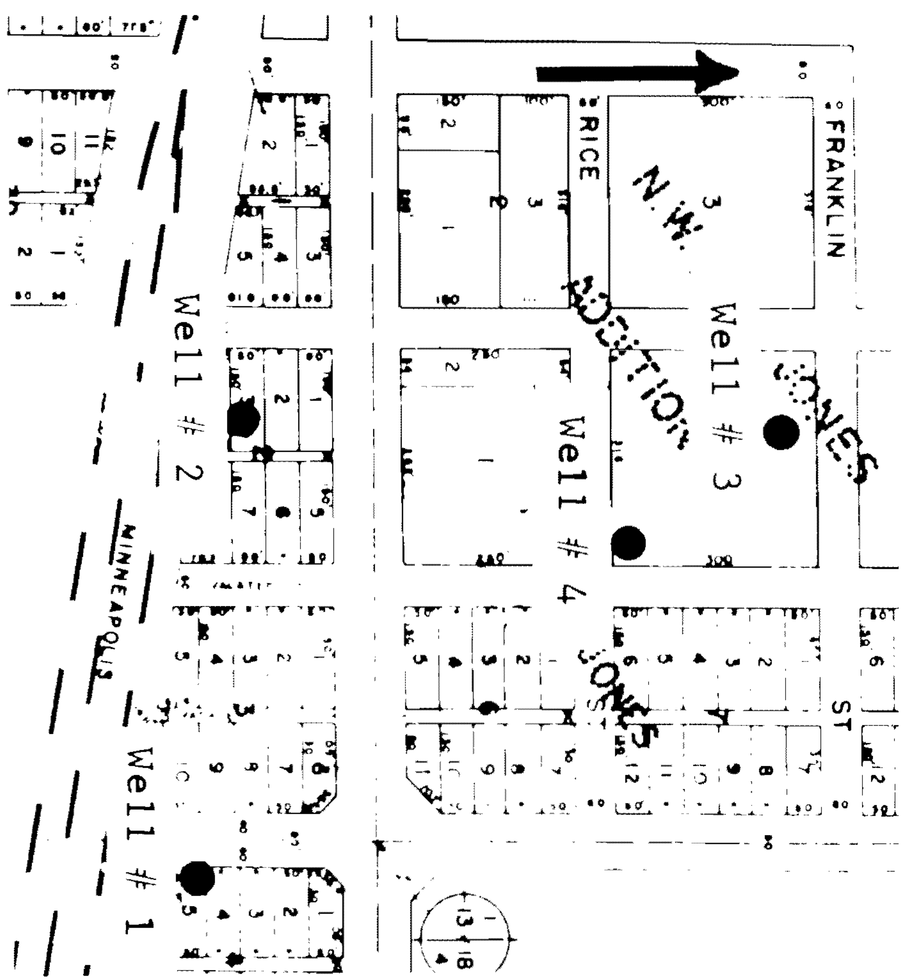


Fig. 2. Location of wells - Adrian

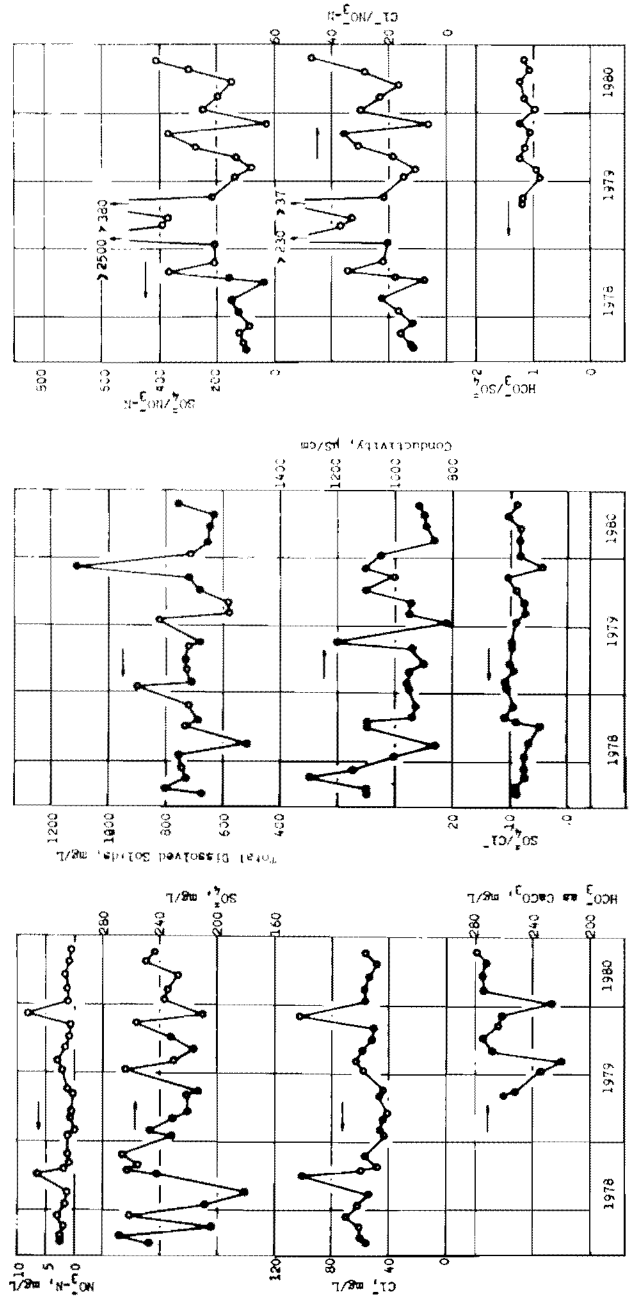


Fig. 3. Adrian, well 1, analytical results

280 mg/L, with a mean and median value of 260 mg/L; total dissolved solids ranged from 520 to 1100 mg/L, with mean and median values of 720 and 710 mg/L, respectively; conductivity ranged from 820 to 1300 µS/cm, with mean and median values 1000 and 950 µS/cm, respectively; pH ranged from 6.6 to 8.0 with a median value of 7.4; sulfate/chloride ratios ranged from 4.1 to 11 with mean and median values of 8.6 and 8.9, respectively; sulfate/nitrate-nitrogen values ranged from 26 to >2500, with mean and median values of >310 and 200, respectively; chloride/nitrate-nitrogen values ranged from 6.2 to >230, with mean and median values of >33 to 22, respectively; and bicarbonate alkalinity/sulfate values ranged from 0.89 to 1.2, with mean and median values of 1.1 and 1.2, respectively.

3.2.2. Well 2

The concentrations observed in Well 2 are shown in Fig. 4 along with the calculated ratios. The results are summarized as follows: sulfate concentrations ranged from 73 to 200 mg/L, with mean and median values of 140 and 150 mg/L, respectively; chloride concentrations varied from 36 to 170 mg/L, with mean and median values of 110 and 120 mg/L, respectively; nitrate-nitrogen concentrations ranged from 2.4 to 100 mg/L, with mean and median values of 20 and 14 mg/L, respectively; bicarbonate alkalinity levels varied from 220 to 350 mg/L, with mean and median values of 290 and 310 mg/L, respectively; total dissolved solids ranged from 530 to 1400 mg/L, with mean and median concentrations of 900 and 890 mg/L, respectively; conductivity ranged from 640 to 2000 µS/cm, with mean and median levels of 1300 and 1400 µS/cm, respectively; pH ranged from 7.0 to 7.8 with a median value of 7.5; sulfate/chloride ratios ranged from 0.65 to 2.9, with mean and median values of 1.3 and 1.2, respectively; sulfate/nitrate-nitrogen ranged from 2 to 40, with mean and median values of 12 and 9.2, respectively; chloride/nitrate-nitrogen values ranged from 1.7 to 22, with mean and median values of 9.0 and 8.3, respectively; and bicarbonate alkalinity/sulfate values ranged from 1.4 to 4.4, with mean and median values of 2.6 and 2.1, respectively.

3.2.3. Well 3

Concentrations measured for waters from Well 3 are indicated in Fig. 5 along with the calculated ratios. The results are summarized as follows: sulfate concentrations ranged from 130 to 220 mg/L, with mean and median concentrations of 180 mg/L; chloride concentrations ranged from 100 to 180 mg/L, with mean and median concentrations of 140 mg/L; nitrate-nitrogen levels ranged from 5.1 to 16 mg/L, with mean and median values of 10 mg/L; bicarbonate alkalinity concentrations ranged from 240 to 300 mg/L, with mean and median concentrations of 270 and 280 mg/L, respectively; total dissolved solids ranged from 720 to 1200 mg/L, with mean and median concentrations of 920 mg/L; conductivity ranged from 1100 to 1700 µS/cm, with mean and median values of 1400 µS/cm; pH ranged from 7.0 to 7.8 with a median value of 7.5; the sulfate/chloride ratio ranged from 0.76 to 2.1 with mean and median values of 1.3 and 1.2, respectively; sulfate/nitrate-nitrogen ranged from 7.8 to 30, with mean and median values of 19 and 18, respectively; chloride/nitrate-nitrogen ranged from 6.7 to 30, with mean and median values of 17 and 16, respectively; and bicarbonate alkalinity/sulfate ranged from 1.2 to 2.3 with mean and median values of 1.5 and 1.4, respectively.

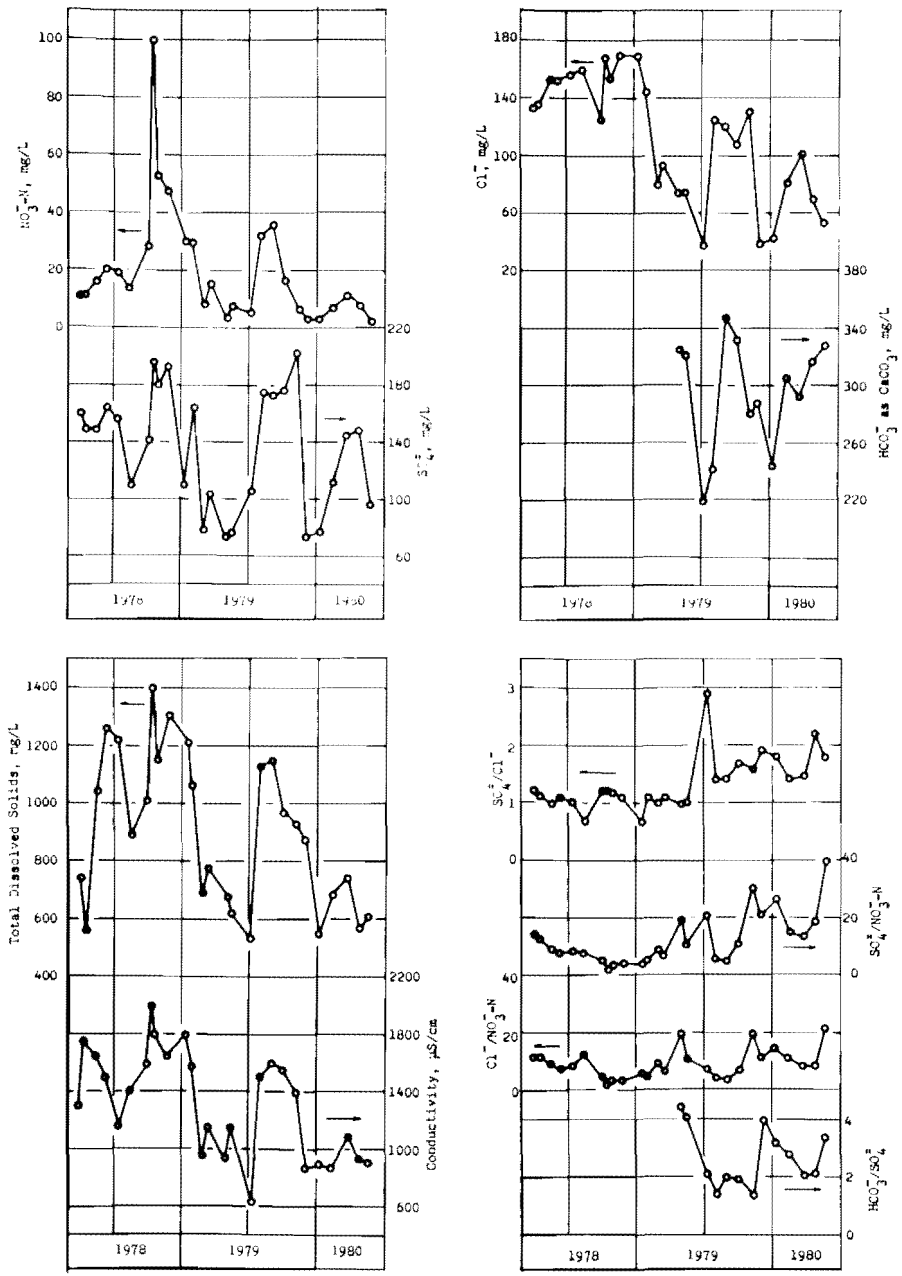


Fig. 4. Adrian, well 2, analytical results

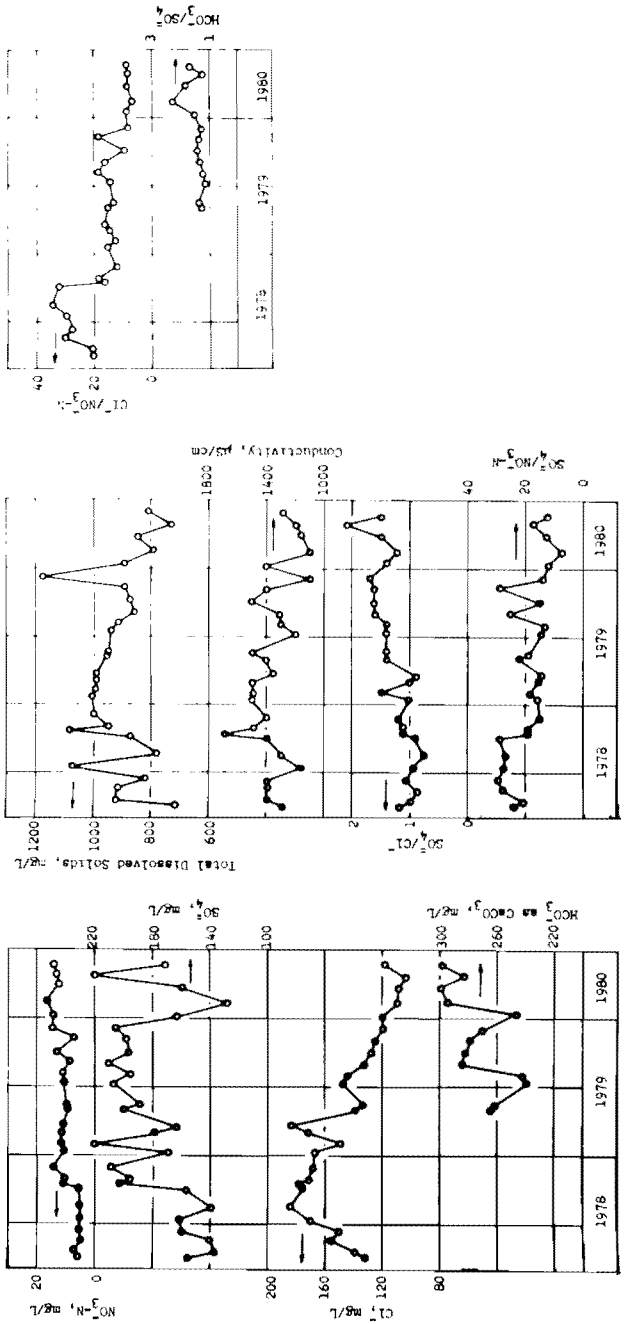


Fig. 5. Adrian, well 3, analytical results

3.2.4. Well 4

Measured concentrations are shown in Fig. 6 along with calculated ratios of anions. The results are summarized as follows: sulfate concentrations ranged from 180 to 290 mg/L, with mean and median concentrations of 220 and 210 mg/L, respectively; chloride ranged from 92 to 230 mg/L, with mean and median concentrations of 150 and 140 mg/L, respectively; nitrate-nitrogen ranged from 6.4 to 16 mg/L, with mean and median values of 11 mg/L; bicarbonate alkalinity ranged from 230 to 280 mg/L, with mean and median concentrations of 260 and 270 mg/L, respectively; total dissolved solids ranged from 690 to 1300 mg/L, with mean and median values of 950 and 940 mg/L, respectively; conductivity ranged from 1100 to 1700 µS/cm, with mean and median values of 1400 µS/cm; pH ranged from 7.0 to 7.8 with a median value of 7.5; sulfate/chloride ranged from 0.86 to 2.4, with mean and median values of 1.5; sulfate/nitrate-nitrogen ranged from 14 to 33, with mean and median values of 20 and 18, respectively; chloride/nitrate-nitrogen ranged from 7.0 to 32, with mean and median values of 15 and 11, respectively; and bicarbonate alkalinity/sulfate ranged from 0.97 to 1.5, with mean and median values of 1.2.

3.2.5. Distribution System - Power Plant Tap

The results are plotted in Fig. 7, and are summarized below: sulfate concentrates ranged from 190 to 280 mg/L, with mean and median values of 230 mg/L; chloride ranged from 21 to 180 mg/L, with mean and median values of 37 and 30 mg/L, respectively; nitrate-nitrogen ranged from 0.54 to 12 mg/L, with mean and median values of 2.5 and 1.7 mg/L, respectively; bicarbonate alkalinity ranged from 220 to 300 mg/L, with mean and median values of 260 and 270 mg/L, respectively; total dissolved solids ranged from 540 to 900 mg/L, with mean and median values of 720 mg/L; conductivity ranged from 860 to 1500 µS/cm, with mean and median values of 1000 to 980 µS/cm, respectively; pH ranged from 6.5 to 8.0 with a median value of 7.4; sulfate/chloride ranged from 1.1 to 12, with mean and median values of 7.6; sulfate/nitrate-nitrogen ranged from 160 to 450, with mean and median values of 170 and 140, respectively; chloride/nitrate-nitrogen ranged from 7.4 to 47, with mean and median values of 21 and 18, respectively; and bicarbonate alkalinity/sulfate ranged from 0.86 to 1.4, with mean and median values of 1.2.

3.2.6. Distribution System - Public School Kitchen Tap

Results have been plotted in Fig. 8, and are summarized as follows: sulfate concentrations ranged from 140 to 240 mg/L, with mean and median values of 180 mg/L; chloride ranged from 34 to 180 mg/L, with mean and median values of 130 mg/L; nitrate-nitrogen ranged from 2.7 to 15 mg/L, with mean and median values of 9.7 and 9.3 mg/L, respectively; bicarbonate alkalinity ranged from 220 and 290 mg/L, with mean and median values of 270 and 280 mg/L, respectively; total dissolved solids ranged from 700 to 1200 mg/L, with mean and median values of 890 and 880 mg/L, respectively; conductivity ranged from 1100 to 1600 µS/cm with mean and median values of 1300 µS/cm; pH ranged from 7.1 to 7.8, with a median value of 7.4; sulfate/chloride ranged from 0.79 to 6.6, with mean and median values of 1.6 and 1.3, respectively; sulfate/nitrate-nitrogen ranged from 11 to 83 with mean and median values of 22 and 20, respectively; chloride/nitrate-nitrogen ranged from 7.3 to 26, with mean and median values of 15 and 13, respectively;

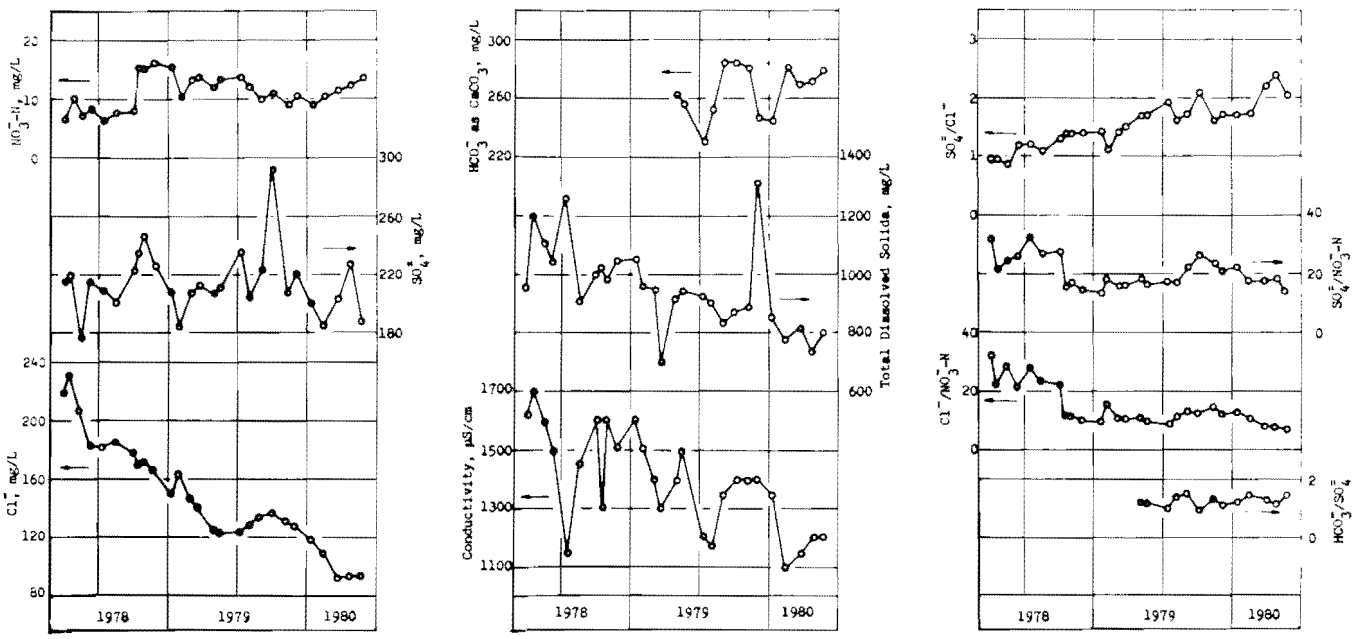


Fig. 6. Adrian, well 4, analytical results

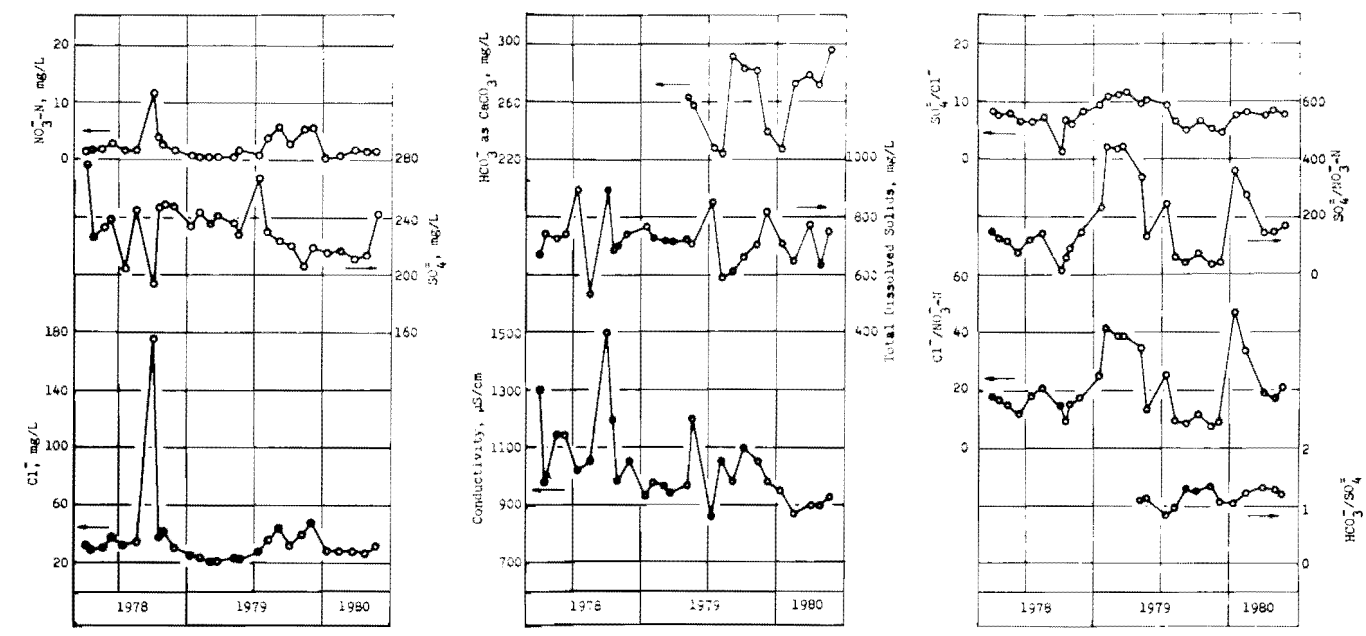


Fig. 7. Adrian, distribution system, power plant tap, analytical results

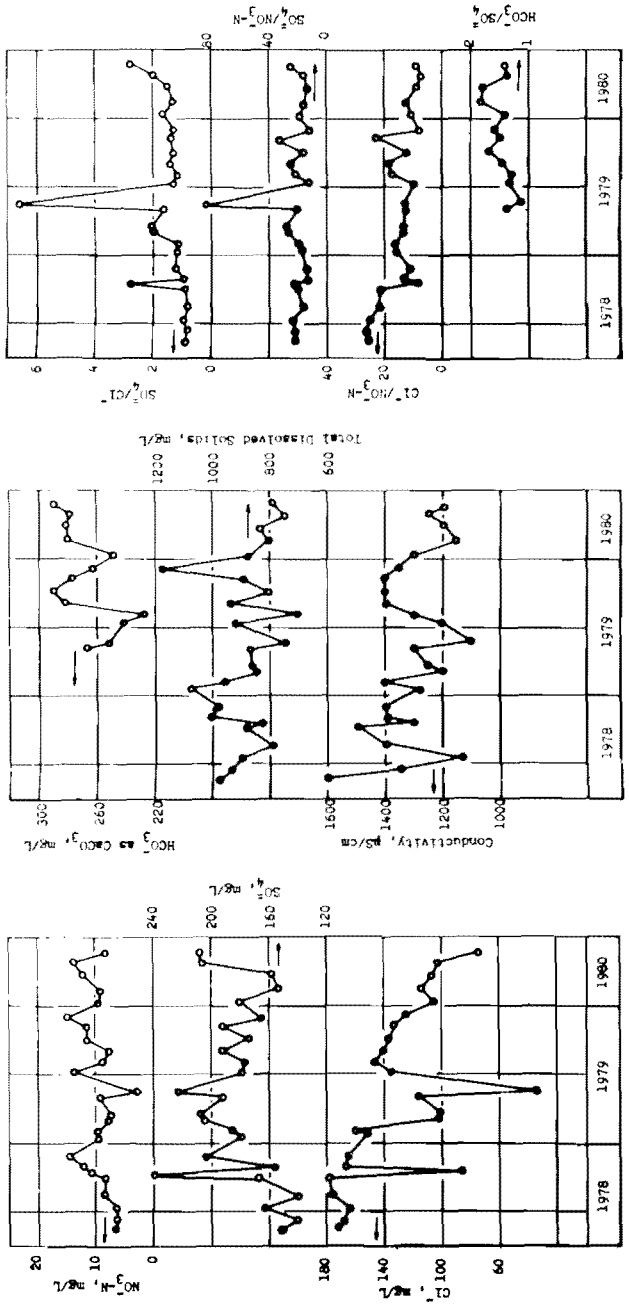


Fig. 8. Adrian, distribution system, public school, analytical results

and bicarbonate alkalinity/sulfate ranged from 1.1 and 1.8, with mean and median values of 1.5 and 1.4, respectively.

3.3. Discussion

Data reported by the Minnesota State Department of Health[11] for these wells follows: Well 1 (3/68) sulfate 300 mg/L, chloride 22 mg/L, nitrate-nitrogen 4.3 mg/L, bicarbonate alkalinity 280 mg/L, and pH 7.2; calculated ratios were sulfate/chloride 14, sulfate/nitrate-nitrogen 70, chloride/nitrate-nitrogen 5.1, and bicarbonate alkalinity/sulfate 0.93; Well 2 (3/68) sulfate 150 mg/L, chloride 52 mg/L, nitrate-nitrogen 4.5 mg/L, bicarbonate alkalinity 330 mg/L, and pH 7.0; calculated ratios were sulfate/chloride 2.9, sulfate/nitrate-nitrogen 33, chloride/nitrate-nitrogen 12, and bicarbonate/sulfate 2.2; Well 3 (3/68 and 3/73) sulfate 230 and 200 mg/L, chloride 71 and 220 mg/L, nitrate-nitrogen 4.6 and 7.2 mg/L, bicarbonate 270 and 370 mg/L, total dissolved solids 1000 mg/L (3/73), conductivity 1500 µS/cm (3/73), pH 7.1 and 7.6, ratios calculated were sulfate/chloride 3.2 and 0.91, sulfate/nitrate-nitrogen 50 and 28, chloride/ nitrate-nitrogen 15 and 31, and bicarbonate/sulfate 1.2 and 1.8; Well 4 (6/58, 3/68, 3/73, respectively) sulfate 183, 240 and 180 mg/L, chloride 24, 210, and 100 mg/L, nitrate-nitrogen 5.0, 9.9, and 14 mg/L, bicarbonate 311, 290, and 300 mg/L, total dissolved solids 600 and 890 mg/L (6/58 and 3/73), conductivity 890 and 1400 µS/cm (6/58 and 3/73), pH 7.3, 7.0, and 7.6, ratios calculated were sulfate/chloride 7.6, 1.1, and 1.8, sulfate/nitrate-nitrogen 37, 24, and 13, chloride/nitrate-nitrogen 4.8, 21, and 7.1, and bicarbonate/sulfate 1.7, 1.2, and 1.7.

With regard to sulfate concentrations in the four wells, highest values were reported for Wells 1 and 4 (means 240 and 220 mg/L), lower values were reported for Wells 2 and 3 (means 140 and 180 mg/L) and with the power plant distribution system samples conforming with those of Well 1 (means 240 and 230 mg/L, respectively), and those collected at the public school showed values representing an admixture primarily from Wells 3 and 4 and Well 2 when it was added to the distribution system (mean public school 180, Well 3 180, Well 4 220, and Well 2 140 mg/L). The overall range in values for the four wells was 73 and 290 mg/L compared to previously reported values of 180 to 300 mg/L, indicating little change in concentrations. Eight of the sulfate samples taken from Well 1 and 1 from Well 4 exceeded the Secondary Drinking Water Standard for sulfates of <250 mg/L.[10]

Chloride concentrations were lowest in Well 1 and the power plant distribution system samples (means 29 and 37 mg/L, respectively); mean values for Wells 2, 3, and 4 and the public school distribution samples were 110, 140, 150 and 130 mg/L, respectively. Our overall values ranged from 20 to 230 mg/L, whereas previously reported data indicated individual values ranging from 22 to 220 mg/L. All of the measured values were within the Secondary Drinking Water Standard for chlorides of ≤ 250 mg/L.

Nitrate-nitrogen concentrations were highest in Well 2, and as previously noted this well was not used after November 1978, but was sampled throughout the study period with the waters being discharged to an adjacent sewer. Concentrations in Well 2 ranged from 2.4 to 100 mg/L, whereas the other wells ranged from <0.1 to 16 mg/L. Lowest mean values were reported for Well 1 (<1.8 mg/L); mean values for Wells 3 and 4 were 10 and 11 mg/L, respectively. Again the distribution system sample taken at the power

plant reflected the concentrations in Well 1 and that at the public school the concentrations in Wells 3 and 4, and Well 2, when it was discharging into the distribution system. Overall distribution sample means met the National Interim Primary Standard in Drinking Water for nitrate-nitrogen (≤10 mg/L), but individual samples exceeded this concentration (Well 3, 16 of 27 samples, Well 4, 19/27 samples, power plant distribution system samples 1/27, public school distribution system samples 9/25, and Well 2, 17/27 samples. Excluding the results reported for Well 2, the nitrate-nitrogen concentrations ranged from <0.1 to 16 mg/L, which can be compared to previously reported concentrations of 4.3 to 14 mg/L.

All bicarbonate alkalinity concentration means were similar ranging from 260 to 290 mg/L, whereas overall values ranged from 220 to 350 mg/L; compared with previously reported values of 270 to 370 mg/L.

Except for the total dissolved solids values reported for Well 1 (mean 720 mg/L), all of the other values were similar (means Well 2, 900, Well 3, 920, and Well 4, 940 mg/L). The two distribution system samples again reflected concentrations in Well 1 and Wells 3 and 4 respectively. Overall, the values obtained ranged from 520 to 1400 mg/L compared to previously reported values of 600 to 1000 mg/L. All samples collected exceeded the Secondary Drinking Water Standard for total dissolved solids of ≤500 mg/L.

Conductivity values generally followed total dissolved solids values, and ranged from 640 to 1700 μS/cm compared to previously reported values of 890 to 1500 μS/cm.

Median pH values for all well and distribution system samples ranged from 7.4 to 7.5, with overall ranges of 6.6 to 8.0 compared to previously reported values of 7.0 to 7.6.

With regard to the sulfate/chloride ratios, they were highest in Well 1 and the power plant distribution system samples (means 8.6 and 7.6, respectively) and similar in Wells 2, 3, and 4, and the public school distribution system samples (means 1.3, 1.3, 1.5, and 1.6). Compared to values calculated from previously reported concentrations (range 0.91 to 3.2), our values ranged from 0.65 to 11 overall. Sulfate/nitrate-nitrogen values are dependent to a great extent on the nitrate-nitrogen levels found in Well 1 and the power plant samples which had higher ratios (means >310 and 170, respectively), and values from Wells 3 and 4 and the public school samples which were lower (means of 19, 20, and 22, respectively). Well 2 had a mean value of 12. Values calculated from previously reported analyses ranged from 13 to 70; not too different from our calculated values. Chloride/nitrate-nitrogen values were somewhat similar in that highest ratios were reported for Well 1 and the power plant distribution system samples (means >33 and 21) compared to those calculated for Wells 3 and 4, and the public school distribution samples and Well 2 (means, respectively, 17, 15, 15, and 9.0). Calculated ratios from previous data ranged from 4.8 to 31. Bicarbonate/sulfate values were consistent except for Well 2 (means: Well 1, 1.1, Well 3, 1.5, Well 4, 1.2, power plant distributions system, 1.2, public school distributions system, 1.5, and Well 2, 2.6). Ratios calculated from previously recorded values ranged from 0.93 to 2.2.

3.4. Conclusions

Based upon the data presented, the following conclusions are warranted:

1. Even though the four wells are not too far apart, they exhibit rather different water quality characteristics. For example, Well 1 is highest in sulfate and lowest in total dissolved solids and conductivity, Well 2, highest in nitrate-nitrogen, Wells 3 and 4, highest in chlorides. These differences probably reflect proximity to given sources of surficial and groundwater contamination from differing land use practices. In addition, the ratios of anions, even though differences are not large, indicate a difference in Well 1 compared to the other three wells, except for bicarbonate/sulfate.

2. The distribution system sampling location(s) reflect proximity to well source. The differences shown for the two distribution system samples collected indicate that sampling locations should be carefully selected to obtain a full-range of water quality consumed by the public.

3. A number of individual samples from Wells 2, 3, and 4 showed concentrations of nitrate-nitrogen exceeding the recommended maximum concentrations limit of 10 mg/L. Since the recommended frequency for analysis of inorganic constituents in water is once every three years, it is evident that, where marked fluctuations in concentration occur, such infrequent analyses do not provide information on seasonal and other changes which may affect the concentrations observed.

4. The increasing concentration of nitrate-nitrogen, in particular in Well 2, and subsequently in Wells 3 and 4, prompted the Village of Adrian to declare that the water not be used in the preparation of infant formula, because of the potential for methemoglobinemia, and that sources low in nitrate-nitrogen be used.

5. Several samples exceeded the secondary drinking water regulation with regard to the recommended sulfate concentration (≤250 mg/L), and all samples collected exceeded the recommended total dissolved solids concentration of 500 mg/L.

6. Blending of water, that is pumping a larger increment from wells lower in a given constituent, permits meeting overall water quality, in this case increased pumping from Well 1 in contrast to Wells 3 and 4, results in a lower concentration of nitrate-nitrogen in the municipal supply. If lower concentrations cannot be obtained through blending, only two alternatives are available -- treat the existing sources to remove the objectionable agent (expensive in the case of anions) or finding more suitable sources of water supply.

4.0. LEOTA

4.1. Introduction

The Leota water supply is privately owned and provides water for a population of 125 (1970) census). There are 42 service connections and the average consumption was reported to be 19,000 gal/day.[11] This is equivalent

to 152 gal/capita-day or 452 gal/service connection-day. The dug well, installed in 1968, is 39 ft deep, is equipped with a submersible pump of 390 gpm capacity, and 11,000 gal of ground storage is provided. There is no treatment of the water prior to discharge into the distribution system.

Samples were taken at a kitchen tap or from a hose bib located on the west side of the water superintendent's home.

4.2. Results

The results are plotted in Fig. 9, and are summarized as follows: sulfate concentrations ranged from 100 to 150 mg/L, with mean and median values of 130 mg/L; chlorides ranged from 14 to 36 mg/L, with mean and median values of 27 and 28 mg/L, respectively; nitrate-nitrogen concentrations ranged from 2.7 to 13 mg/L, with mean and median values of 7.8 and 7.6 mg/L, respectively; bicarbonate alkalinity ranged from 250 to 310 mg/L, with mean and median values of 280 mg/L; total dissolved solids ranged from 450 to 700 mg/L, with mean and median concentrations of 630 and 640 mg/L, respectively; conductivity ranged from 740 to 1100 µS/cm, with mean and median values of 890 µS/cm; and pH ranged from 6.8 to 8.0, with a median value of 7.7. Computed ratios were: sulfate/chloride, range 2.8 to 8.6, with mean and median values of 5.2 and 5.0, respectively; sulfate/nitrate-nitrogen, range 11 to 47, with mean and median values of 19 and 17, respectively; chloride to nitrate-nitrogen, range 1.6 to 8.1, with mean and median values of 3.9 and 3.2, respectively; and bicarbonate/sulfate, range 1.7 to 3.0, with a mean and median value of 2.2.

4.3 Discussion

One set of analyses for a sample collected in December 1971 was previously recorded.[11] Concentrations were: sulfate 120 mg/L, chloride 20 mg/L, nitrate-nitrogen 12 mg/L, total dissolved solids 640 mg/L, bicarbonate alkalinity 330 mg/L, and pH 7.3. Ratios calculated from these values were: sulfate/chloride, 1.6; sulfate/nitrate-nitrogen, 10, chloride/nitrate-nitrogen, 1.7; and bicarbonate/sulfate, 2.8. A sample collected on March 15, 1978 showed a nitrate-nitrogen concentration of 9.4 mg/L. The current series of results differed slightly from the previously reported single sample.

4.4. Conclusions

The following conclusions are based upon the data presented.

1. Five of the 27 samples collected for nitrate-nitrogen exceeded the recommended primary interim drinking water standard of 10 mg/L. Twenty-six of 27 samples exceeded the secondary recommended value of 500 mg/L for total dissolved solids.

2. Chloride concentration increased gradually during our study from a value of 14 to 36 mg/L, which may be due to the presence of septic tank discharges contaminating the ground water aquifer or the use of road salt during winter months.

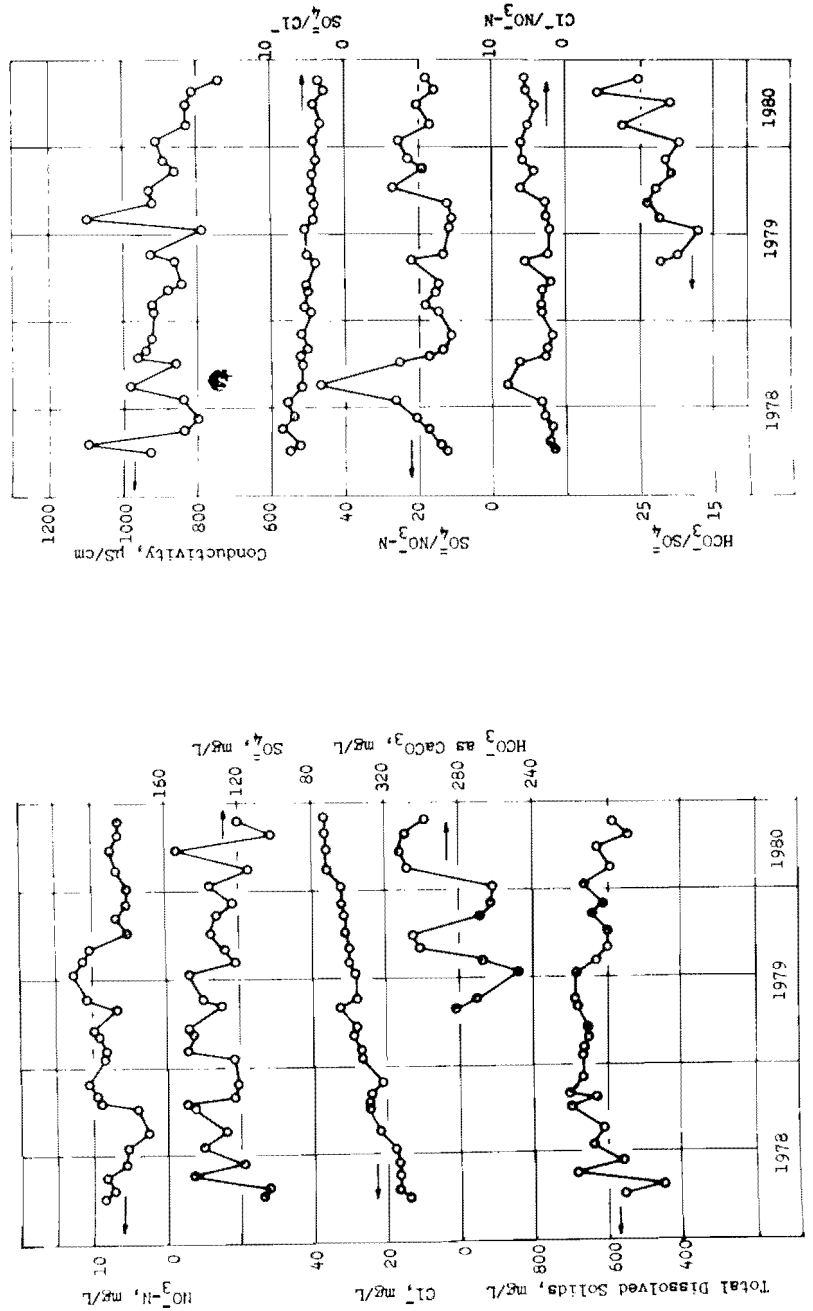


Fig. 9. Ivora, distribution system, analytical results

5.0. EDGERTON

5.1. Introduction

Edgerton had a reported population of 1119 in 1970. It is served by a municipal water supply through 350 service connections. Average daily consumption was 40,000 gal (36 gal/capita-day, and 114 gal/service connection-day). Some main wells are identified, [11] but several of these are no longer in use or productive. In 1976, to augment the quanitity and to improve the quality, a bored, gravel packed well was constructed, which is 46 ft deep and equipped with a submersible pump of 150 gpm capacity. This well is identified as Well 10 in our study. Elevated storage of 37,000 gal and ground storage of 100,000 gal are available.

Several shallow wells (<46 ft deep) serve the water supply needs of Edgerton. These currently include two individual wells (Wells 1 and 10) and a cluster of wells (Well 2). In addition, a well located in the Municipal Garage is used occasionally, particularly during the summer, to meet the expanded water supply needs of the community. A sample of water from the distribution system was collected from a cold water tap located in the Chevrolet Sales and Service building on Main Street.

5.2. Results

5.2.1. Well 1

The results are plotted in Fig. 10, and summarized below. Sulfate concentrations ranged from 61 to 130 mg/L, with mean and median values of 99 and 96 mg/L, respectively; chlorides ranged from 14 to 60 mg/L, with mean and median values of 34 and 35 mg/L, respectively; nitrate-nitrogen ranged from 4.5 to 17 mg/L, with mean and median values of 11 mg/L; bicarbonate alkalinity ranged from 180 to 310 mg/L, with mean and median values of 250 and 260 mg/L, respectively; total dissolved solids ranged from 340 to 990 mg/L, with mean and median values of 580 and 560 mg/L, respectively; conductivity ranged from 690 to 1100 µS/cm, with mean and median values of 830 and 850 µS/cm, respectively; and pH ranged from 6.8 to 8.4, with a median value of 7.6. Calculated ratios were: sulfate/chloride, range 1.9 to 5.8 with mean and median values of 3.1 and 3.0, respectively; sulfate/nitrate-nitrogen, range 4.4 to 27, with mean and median values of 11 and 9.9, respectively; chloride/nitrate-nitrogen, range 1.0 to 7.8, with mean and median values of 3.6 and 3.3, respectively; and bicarbonate/sulfate, range 1.9 to 3.3, with mean and median values of 2.5 and 2.4, respectively.

5.2.2. Well 2

Our findings are plotted in Fig. 11 and are summarized below. Sulfate concentrations ranged from 74 to 150 mg/L, with mean and median values of 120 mg/L; chloride ranged from 26 to 81 mg/L, with mean and median values of 51 and 48 mg/L, respectively; nitrate-nitrogen ranged from 3.8 to 11 mg/L, with mean and median values of 6.5 and 5.9 mg/L, respectively; bicarbonate alkalinity ranged from 210 to 310 mg/L, with mean and median values of 260 and 280 mg/L, respectively; total dissolved solids ranged from 370 to 810 mg/L, with mean and median values of 620 and 600 mg/L, respectively; conductivity ranged from 760 to 1200 µS/cm, with mean and median values of 890 and 870 µS/cm, respectively; and pH ranged from 6.9 to 8.2, with median value of 7.7. Calculated ratios follow: sulfate/chloride ranged

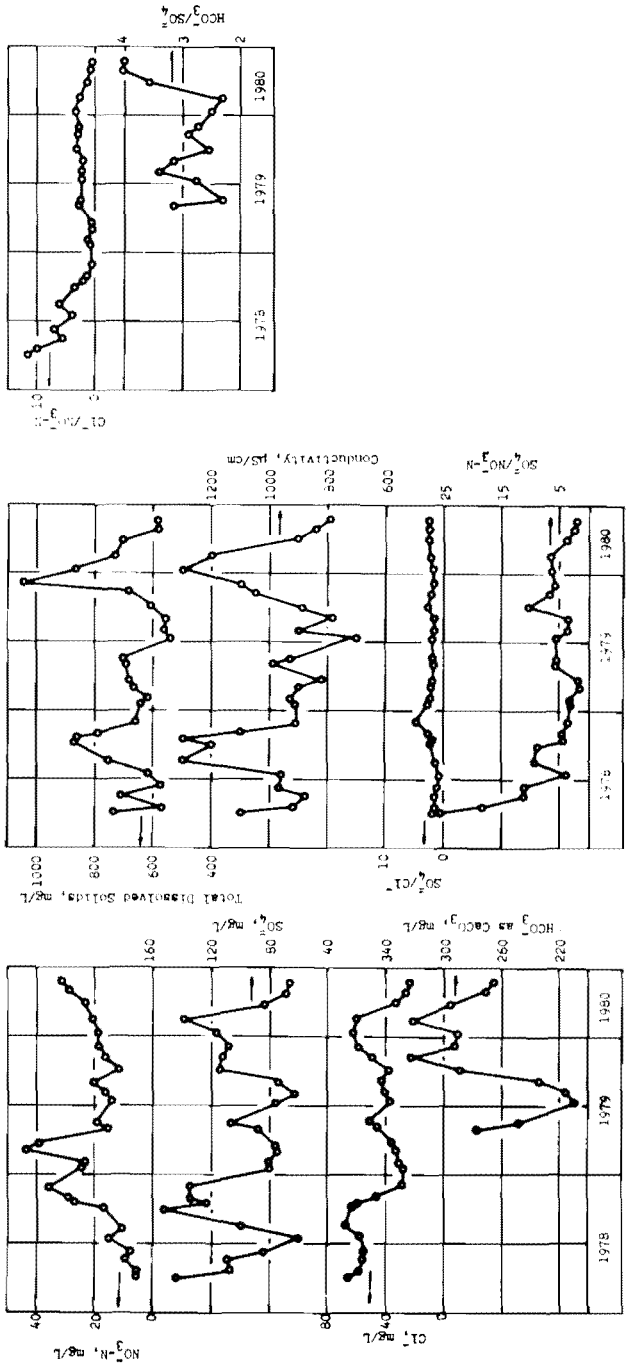
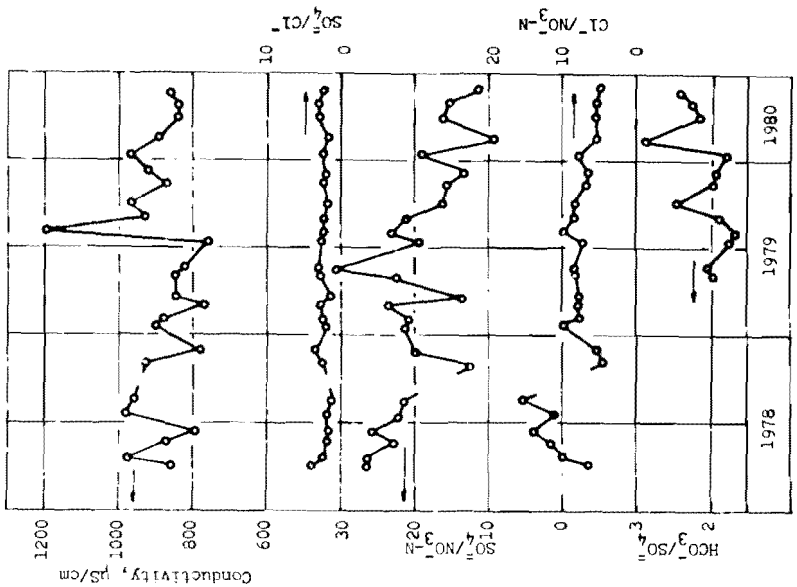


Fig. 10. Edgerton, well 1, analytical results



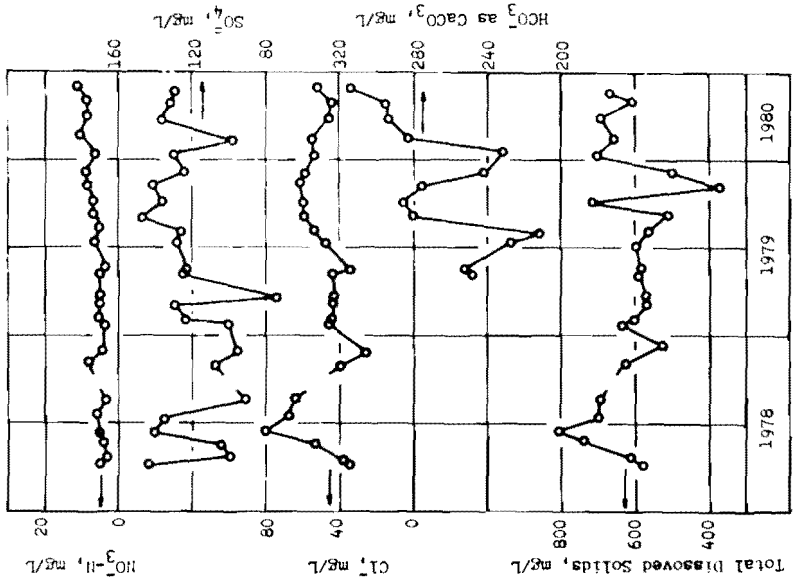


Fig. 11. Edgerton, well 2, analytical results

from 1.4 to 4.1, with mean and median values of 2.5 and 2.4, respectively; sulfate/nitrate-nitrogen ranged from 9.4 to 31 with mean and median values of 20 and 21, respectively; chloride/nitrate-nitrogen ranged from 4.7 to 16 with mean and median values of 8.0 and 8.2, respectively; and bicarbonate/sulfate ranged from 1.7 to 2.9, with mean and median values of 2.1 and 2.0, respectively.

5.2.3. Well 10

Analytical values are plotted in Fig. 12 and are summarized below. Sulfate concentrations ranged from 26 to 77 mg/L, with mean and median values of 57 and 58 mg/L, respectively; chlorides ranged from 4.5 to 10 mg/L, with mean and median concentrations of 6.7 and 7.0 mg/L, respectively; nitrate-nitrogen ranged from 4.6 to 17 mg/L, with mean and median values of 12 and 13 mg/L, respectively; bicarbonate alkalinity ranged from 160 to 470 mg/L, with mean and median values of 220 mg/L; total dissolved solids ranged from 220 to 560 mg/L, with mean and median values of 400 mg/L; conductivity ranged from 550 to 800 µS/cm, with mean and median values of 630 and 620 µS/cm, respectively; and pH ranged from 7.1 to 9.3, with a median value of 7.7. Calculated ratios were: sulfate/chloride, range from 5.3 to 14, with mean and median values of 8.4 and 8.2, respectively; sulfate/nitrate-nitrogen, range from 2.9 to 15, mean and median values of 5.3 and 4.8, respectively; chloride/nitrate-nitrogen, range from 0.35 to 1.1, with mean and median values of 0.62 and 0.60, respectively; and bicarbonate/sulfate, range from 2.3 to 9.3, with mean and median values of 4.1 and 3.5, respectively.

5.2.4. Shop Well

The results obtained are shown in Fig. 13 and are summarized as follows: sulfate concentrations ranged from 60 to 150 mg/L, with mean and median values of 99 and 100 mg/L, respectively; chloride ranged from 24 to 68 mg/L, with mean and median values of 47 and 46 mg/L, respectively; nitrate-nitrogen ranged from 5.6 to 44 mg/L, with mean and median values of 20 and 19 mg/L, respectively; bicarbonate alkalinity ranged from 210 to 320 mg/L, with mean and median values of 270 and 280 mg/L, respectively; total dissolved solids ranged from 540 to 1000 mg/L, with mean and median values of 690 mg/L; conductivity ranged from 700 to 1300 µS/cm, with mean and median values of 980 and 930 µS/cm, respectively; and pH ranged from 7.0 to 8.1, with a median value of 7.6. Calculated ratios were: sulfate/chloride, range 1.0 to 4.9, with mean and median values of 2.2 and 2.1, respectively; sulfate/nitrate-nitrogen, range 1.7 to 26, with mean and median values of 6.7 and 5.5, respectively; chloride/nitrate-nitrogen, range 0.75 to 12, with mean and median values of 3.3 and 2.7 respectively; and bicarbonate/sulfate, range 2.3 to 4.0, with mean and median values of 3.0 and 2.9, respectively.

5.2.5. Distribution System

Results are plotted in Fig. 14 and a summary follows: sulfate concentrations ranged from 33 to 140 mg/L, with mean and median values of 80 and 73 mg/L, respectively; chloride ranged from 6.0 to 54 mg/L, with mean and median values of 20 and 15 mg/L, respectively; nitrate-nitrogen ranged from 6.8 to 17 mg/L, with mean and median values of 11 mg/L; bicarbonate alkalinity ranged from 200 to 310 mg/L, with mean and median values of 240 mg/L; total dissolved solids ranged from 330 to 780 mg/L, with mean and

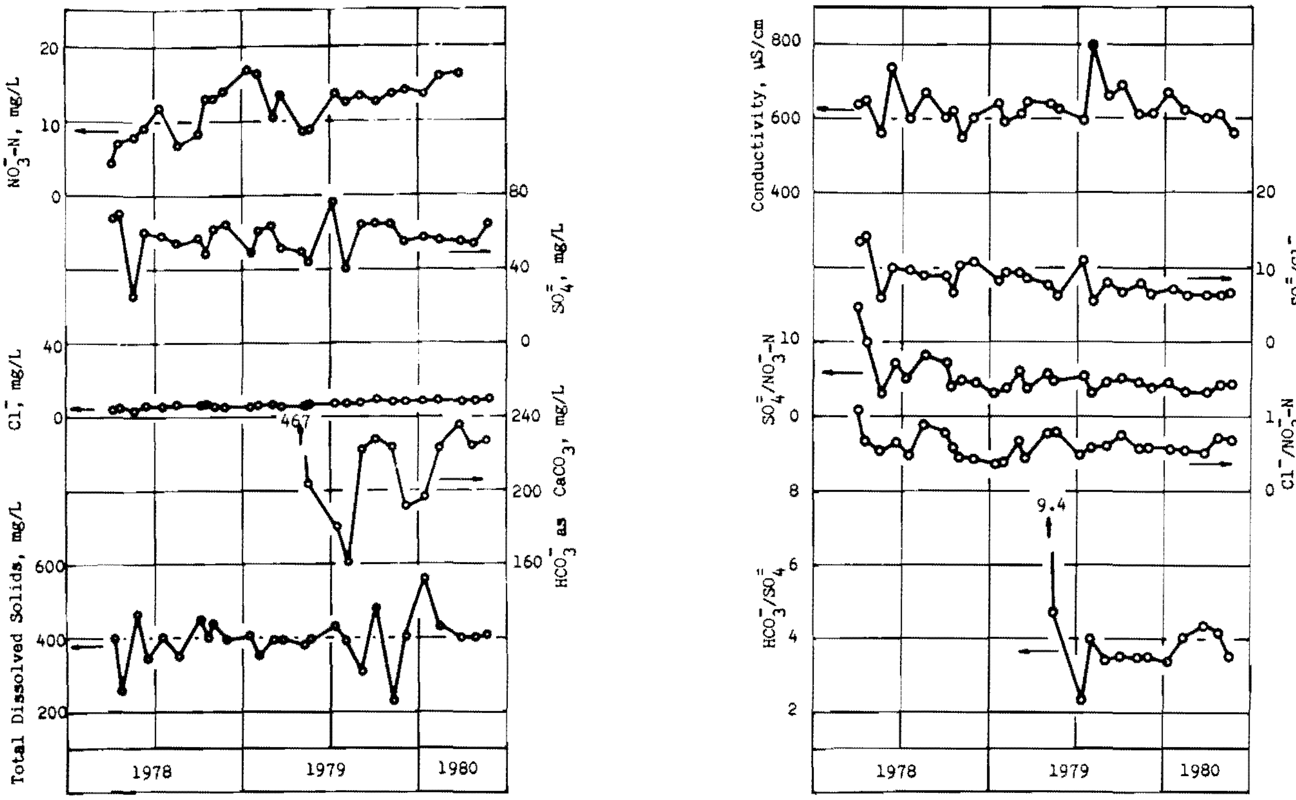


Fig. 12. Edgerton, well 10, analytical results

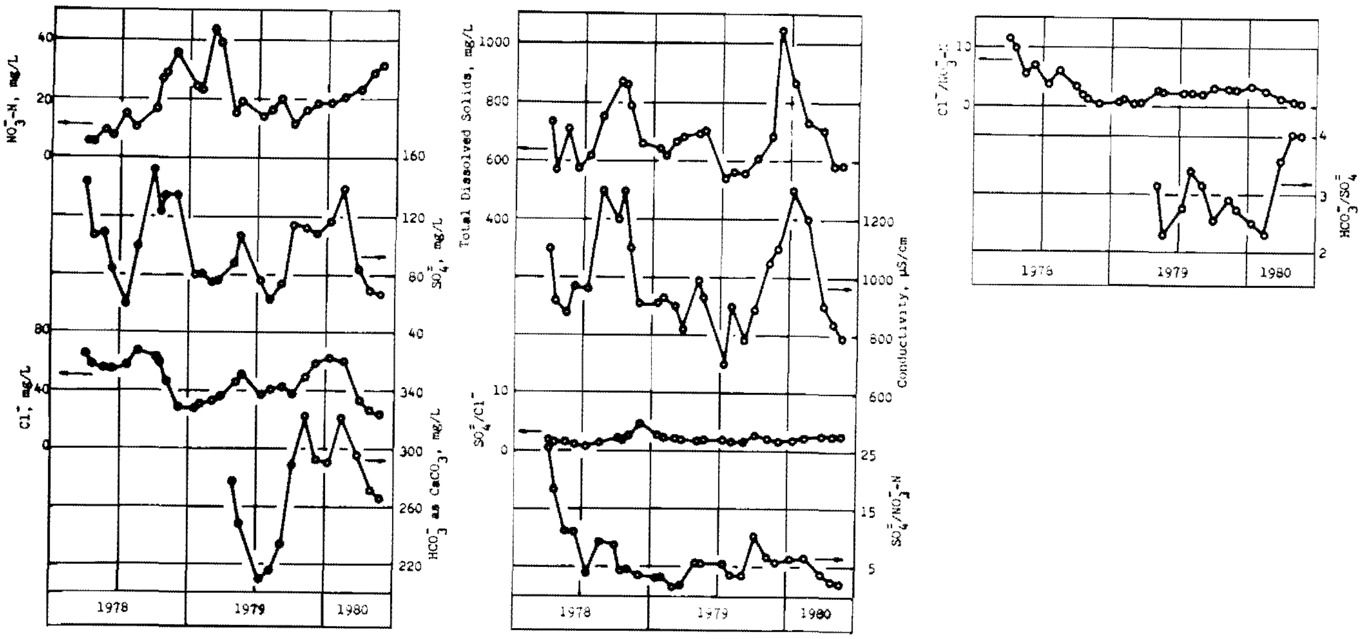


Fig. 13. Edgerton, shop well, analytical results

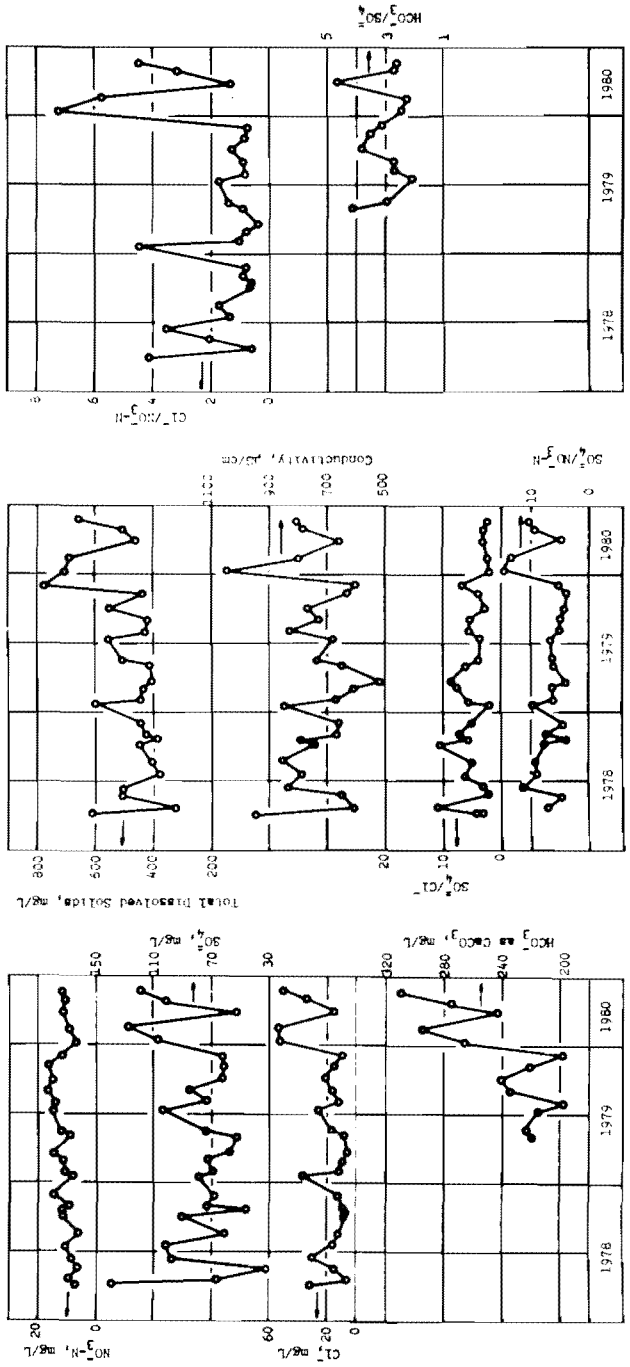


Fig. 14. Edgerton, distribution system, analytical results

median values of 500 and 450 mg/L, respectively; conductivity ranged from 520 to 1000 µS/cm, with mean and median values of 740 µS/cm; and pH ranged from 7.1 to 8.1 with a median value or 7.7. Calculated ratios were: sulfate /chloride, range 2.0 to 11, with a mean and median value of 5.2; sulfate/ nitrate-nitrogen, range 3.8 to 18, with mean and median values of 7.6 and 6.3, respectively; chloride/nitrate-nitrogen, range 0.44 to 7.3, with mean and median values of 2.0 and 1.4, respectively; and bicarbonate/sulfate, range 2.1 to 4.7, with mean and median values of 3.1 and 2.7, respectively.

5.3. Discussion

Because some wells have been abandoned and the grouping of wells, includes these, with the exception of Well 1, it is difficult to make overall comparisons regarding changes in water quality with time. Data are avilable[11] for the dates 12/47, 3/61, and 3/68 for Well 1, and show sulfate concentrations ranging from 46 to 95 mg/L; chloride from 15 to 22 mg/L; nitrate-nitrogen from 8 to 17 mg/L; bicarbonate alkalinity from 250 to 310 mg/L; and pH from 6.4 to 7.4. Calculated ratios ranged as follows: sulfate/chloride 2.6 to 4.3; sulfate/nitrate-nitrogen 3.9 to 5.8; chloride/nitrate-nitrogen 1.3 to 1.9; and bicarbonate/sulfate, 3.2 to 6.7. Based upon these values and our measurements, on the average, sulfate and chloride levels have increased, nitrate-nitrogen levels have remained about the same, bicarbonate is about the same, and pH shows increased alkalinity. For the calculated ratios, sulfate/chloride is about the same indicating that the increases in sulfate and chloride were proportionate, the ratio of sulfate/nitrate-nitrogen and chloride/nitrate-nitrogen show an increase, again reflecting the increased sulfate and chloride concentrations, and bicarbonate/sulfate ratios are comparable.

Lowest concentrations of sulfate were observed in Well 10, higher, but similar values in Well 1 and the Shop Well, and highest levels in Well 2. Lowest chloride concentrations were found in Well 10, but they showed a continuous increase from an initial value of 5.0 to 10 mg/L over the sampling period. Wells 1 and 2 and the Shop Well had average concentrations of 34, 51, and 47 mg/L of chloride, respectively. Well 2 showed the lowest nitrate-nitrogen levels, with similar but higher levels in Wells 1 and 10; highest levels were observed in the Shop Well. Bicarbonate alkalinity averages ranged from 220 to 270 mg/L. Total dissolved solids and conductivity were lowest in Well 10, approximately similar but higher concentrations were reported for Wells 1 and 2, and the highest concentrations were observed in the Shop Well. pH was similar for all wells with median values of 7.6 and 7.7. The various ratios varied as indicated under results, particularly those ratios involving nitrate-nitrogen concentrations.

The distribution system concentrations showed concentrations intermediate between the values reported for Wells 1 and 2 and Well 10, with values closer to those in Well 10, because of its larger contribution to the total volume of water pumped. The Shop Well exerted less influence, since it was used primarily as a standby unit to supply water during periods of increased demand.

5.4. Conclusions

The following conculsions may be drawn upon the results reported.

1. With the exception of Well 2, which exceeded the permissible nitrate-nitrogen concentration in two of the 27 samples collected, all of the other wells exceeded this concentration with greater frequency -- Well 1, 16/27; Well 10, 19/27; and Shop Well, 23/27; the distribution system samples exceeded the permissible concentration in 17/27 samples collected.

2. Except for Well 10 (1/27 samples), many of the other samples collected exceeded the recommended concentration for total dissolved solids -- Well 1, 21/27 samples; Well 2, 24/25 samples, and Shop Well, 27/27; the distribution system showed 12/27 samples exceeding the limit.

3. Well 1 showed a general increase in chloride, Well 2, in sulfates and nitrate-nitrogen, Well 10 in chlorides and nitrate-nitrogen, the Shop Well an increase in nitrate-nitrogen and a decrease in chloride, and the distribution system a slight increase in nitrate-nitrogen.

4. Because of the increasing concentrations of nitrate-nitrogen observed, it would be advisable for the water utility to advise consumers against using the municipal supply for preparing infant formula.

6.0. HARDWICK

6.1. Introduction

The municipally-owned water supply at Hardwick (population 1970 - 273) has 112 service connections with an average daily consumption of 25,000 gal (92 gal/capita-day or 233 gal/service connection-day). A single well is located in the firehouse. It is 410 ft deep, and is served by a 150 gpm vertical turbine pump. No treatment is provided and storage consists of a 10,000 gal pressure tank.

Most samples were collected in the firehouse; three at a gasoline station across the street from the firehouse.

6.2. Results

Results are shown in Fig. 15 and are summarized as follows: sulfate concentrations ranged from 20 to 80 mg/L, with mean and median values of 44 and 40 mg/L, respectively; chloride ranged from 14 to 33 mg/L, with mean and median values of 19 and 18 mg/L, respectively; nitrate-nitrogen ranged from 2.5 to 12 mg/L, with mean and median concentration values of 7.5 and 7.4 mg/L, respectively; bicarbonate alkalinity ranged from 110 to 190 mg/L, with a mean and median value of 160 mg/L; total dissolved solids ranged from 210 to 490 mg/L, with a mean and median value of 310 mg/L; conductivity ranged from 440 to 970 µS/cm, with mean and median values of 580 and 530 µS/cm, respectively; and pH ranged from 7.1 to 8.2, with mean and median value of 7.2. Calculated ratios were: sulfate/chloride, range 0.97 to 4.6, with mean and median values of 2.5 and 2.0, respectively; sulfate/nitrate-nitrogen, range 2.6 to 20, with mean and median values of 6.3 and 5.6, respectively; chloride/nitrate-nitrogen, range 1.4 to 8.0, with mean and median values of 2.7 and 2.5, respectively; and bicarbonate/sulfate, range 1.7 to 5.4, with mean and median values of 3.7 and 3.9, respectively.

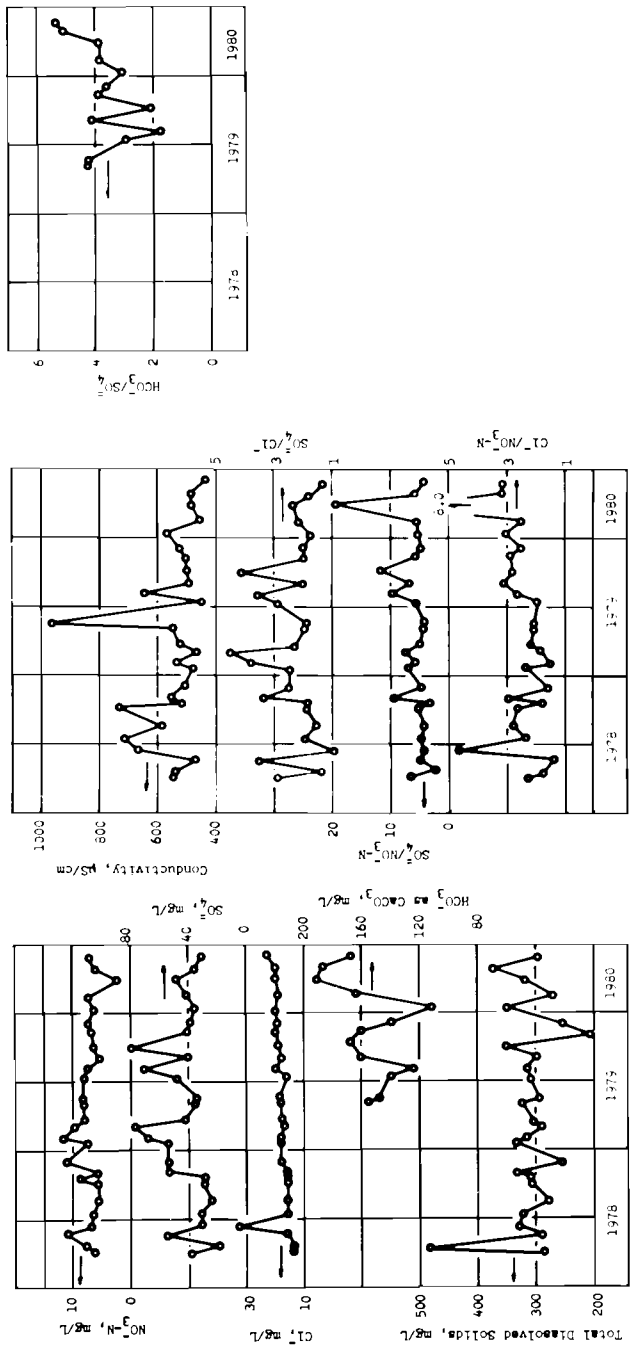


Fig. 15. Hardwick, municipal supply, analytical results

6.3. Discussion

Previous samples were collected in 2/68 and 4/74 and yielded the following results,[11] respectively: sulfate, 28 and 34 mg/L, chloride, 8.5 and 13 mg/L; nitrate-nitrogen, 5.6 and 7.5 mg/L; bicarbonate alkalinity, 300 and 160 mg/L; total dissolved solids, 300 mg/L (4/74); and pH, 6.8 and 6.9. Calculated ratios were respectively: sulfate/chloride, 3.3 and 2.6; sulfate/nitrate-nitrogen, 5.0 and 4.5; chloride/nitrate-nitrogen, 1.5 and 1.7; and bicarbonate/sulfate, 10.7 and 4.7.

Comparing earlier data with our findings show that the sulfate has increased (average 31 to 44 mg/L); chloride has increased (average 11 to 19 mg/L); nitrate-nitrogen has increased (average 6.6 to 7.5 mg/L); bicarbonate apparently decreased (average 230 to 160 mg/L); total dissolved solids has remained the same (average 300 to 310 mg/L); and pH has become more alkaline (6.8 to 7.7). The calculated values also show some changes: sulfate/chloride, average 3.0 to 2.5; sulfate/nitrate-nitrogen, average 4.8 to 6.3; chloride/nitrate-nitrogen, average 1.6 to 2.7; and bicarbonate/sulfate, average 7.7 to 3.7, respectively.

Three of the 27 samples collected exceeded the permissible concentration for nitrate-nitrogen. All other values were within accepted levels, due probably to the greater depth of this well. However, overall there was an increase in the concentration of sulfates, chlorides, and nitrate-nitrogen with time.

6.4. Conclusions

Based upon the results obtained, the following conclusions appear warranted:

1. Even though this well is considerably deeper than any of the other wells sampled, three of the 27 samples collected exceeded the drinking water standard for nitrate-nitrogen reflecting possible surficial or subsurface contaminant movement through cracks and crevices in the overlying geologic formations.

2. There is further evidence of contaminants entering the aquifer as indicated by the apparent increasing concentrations in sulfates and chlorides. The concentration found for these two constituents are still low.

3. Bicarbonate alkalinity was the lowest observed in any well.

7.0. LUVERNE

7.1. Introduction

The Luverne municipal water supply serves a population of 4703 (1970 census) through 1689 service connections. A number of wells are used and several have been replaced making comparisons with earlier results difficult. The average consumption is reported to be 1.2 million gal per day (255 gal/capita-day) or 710 gal/service connection-day.[11] Wells are shallow ranging in depth from 20 to 66 ft, identified as drilled, with the exception of the shallowest which is a dug well. Pumping equipment is characterized as vertical turbine (capacity ranging from 100 to 400 gpm) and

submersible (capacity ranging from 200 to 285 gpm). Treatment consists of iron and maganese removal with chemical additions of lime and alum as required, passage through rapid sand filters (primarily for iron and manganese removal), addition of chlorine gas for disinfection, and application of hydrofluosilicic acid for fluoride treatment. Storage consists of 300,000 gal elevated storage and 2.0 million gal ground storage.

Luverne obtains its water supplies from wells located in two general areas designated as the South and North fields. Seven wells are located in the South Field (Fig. 16) which discharge into a common header leading to Waterworks No. 2 (Fig. 17), and seven wells located in the North Field which discharge into a common header leading to Waterworks No. 1 (Fig. 18).

The area comprising the South Field is adjacent to the Luverne Airport and most of the area is actively farmed. Wells 10, 12, and 12B are in a line along the eastern third of the field, Wells 11 and 13 along the western third of the field parallel to the airport as shown in Fig. 16. Well 9 is located north of the road leading into the airport. Included in the South Field is Well 7, which is located south of Waterworks No. 2, in an area that was used for the disposal of diseased trees and for the disposal of snow (see Fig. 17).

Wells 2, 3, 5A, 6A, and 20A are located in or on the periphery of a park area, Well 19 is located along the north side of the highway opposite the park and Well 21 is located on a knoll north of the Rock River and east of Waterworks No. 1 as shown in Fig. 18. These wells are in the North Field.

Samples were collected from a tap at each of the wells, at the two waterworks following passage through the filters, and from the distribution system -- a cold water tap located at the Standard Gasoline Service Station on the northwest corner of the intersection of U.S. Highway 75 and State Highway 17.

7.2. Results

Results will be presented in two sections, those relating to wells in the South Field and those to wells in the North Field.

7.2.1. South Field

7.2.1.1. Well 7

The results obtained at Well 7 are presented in Fig. 19 and are summarized below. Sulfate concentrations ranged from 32 to 77 mg/L, with mean and median values of 59 and 60 mg/L, respectively; chloride, 98 to 130 mg/L, with mean and median values of 120 mg/L; nitrate-nitrogen, 1.8 to 9.9 mg/L, with mean and median values of 5.7 and 6.1 mg/L, respectively; bicarbonate alkalinity, 230 to 270 mg/L, with mean and median values of 250 and 260 mg/L, respectively; total dissolved solids, 430 to 920 mg/L, with mean and median values of 680 and 650 mg/L, respectively; conductivity, 810 to 1200 µS/cm, with mean and median values of 980 and 930 µS/cm, respectively; and pH, 7.2 to 8.2, with a mean and median value of 7.7. Calculated ratios were: sulfate/chloride, 0.28 to 0.70, with mean and median values of 0.50 and 0.51, respectively; sulfate/nitrate-nitrogen, 4.2 to 33, with mean and median values of 13 and 9.9, respectively; chloride/nitrate-nitrogen, 10 to 69, with mean and median values of 27 and 20, respectively; and bicarbonate/

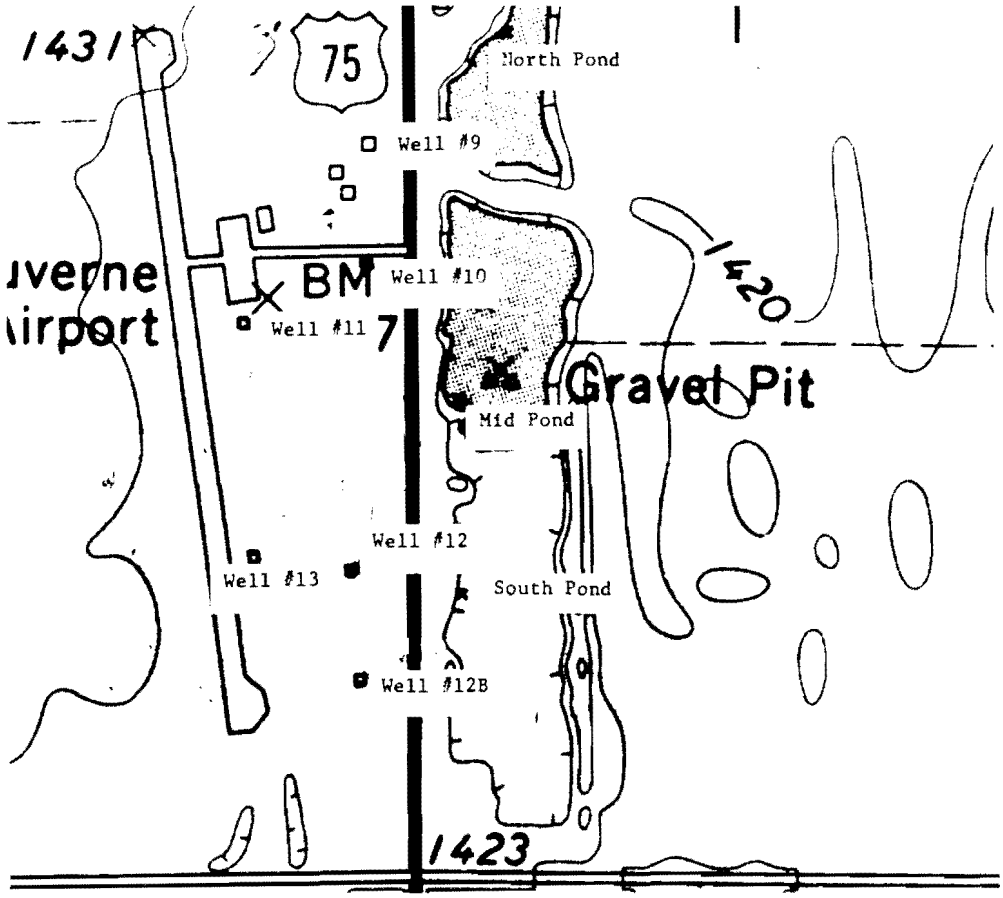


Fig. 16. Luverne, location of wells, south field

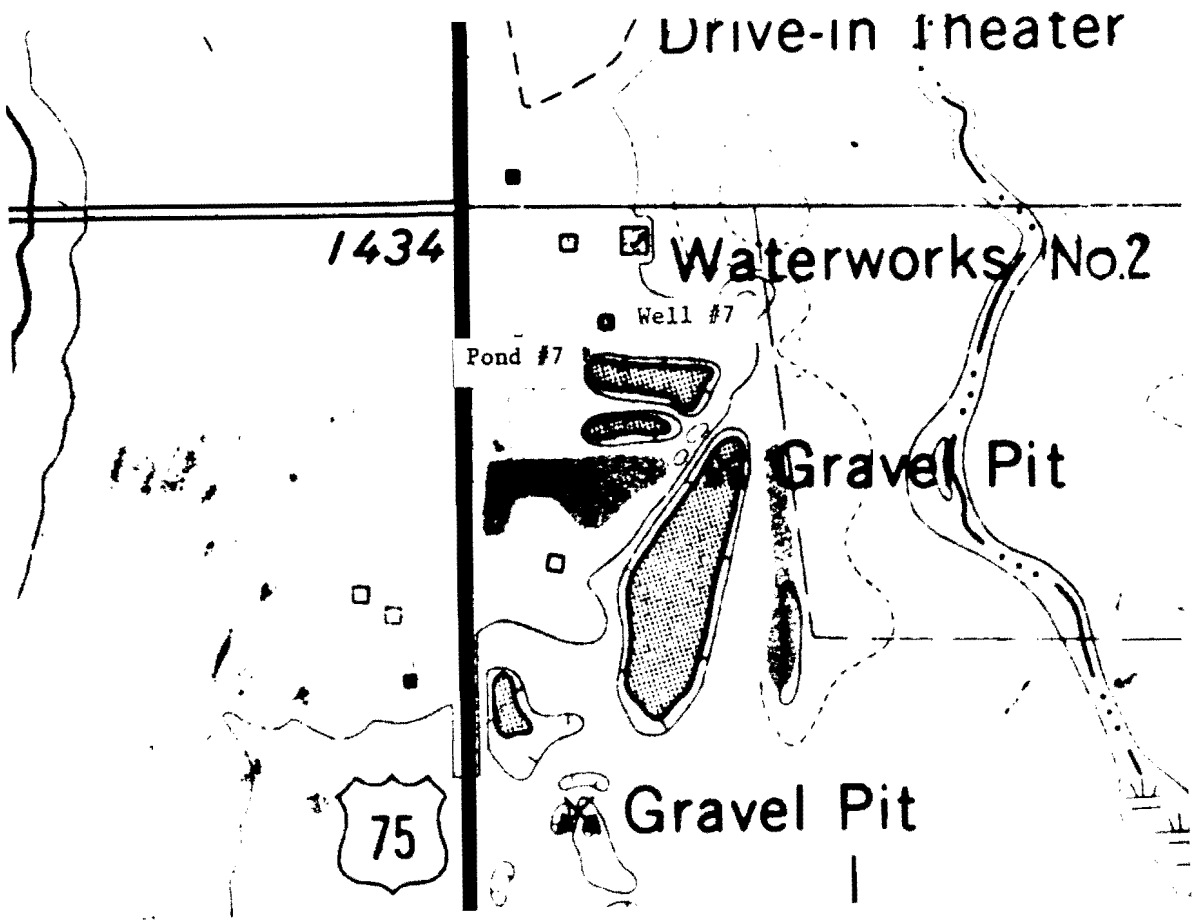


Fig. 17. Luverne, location of well 7 and water works No. 2, south field

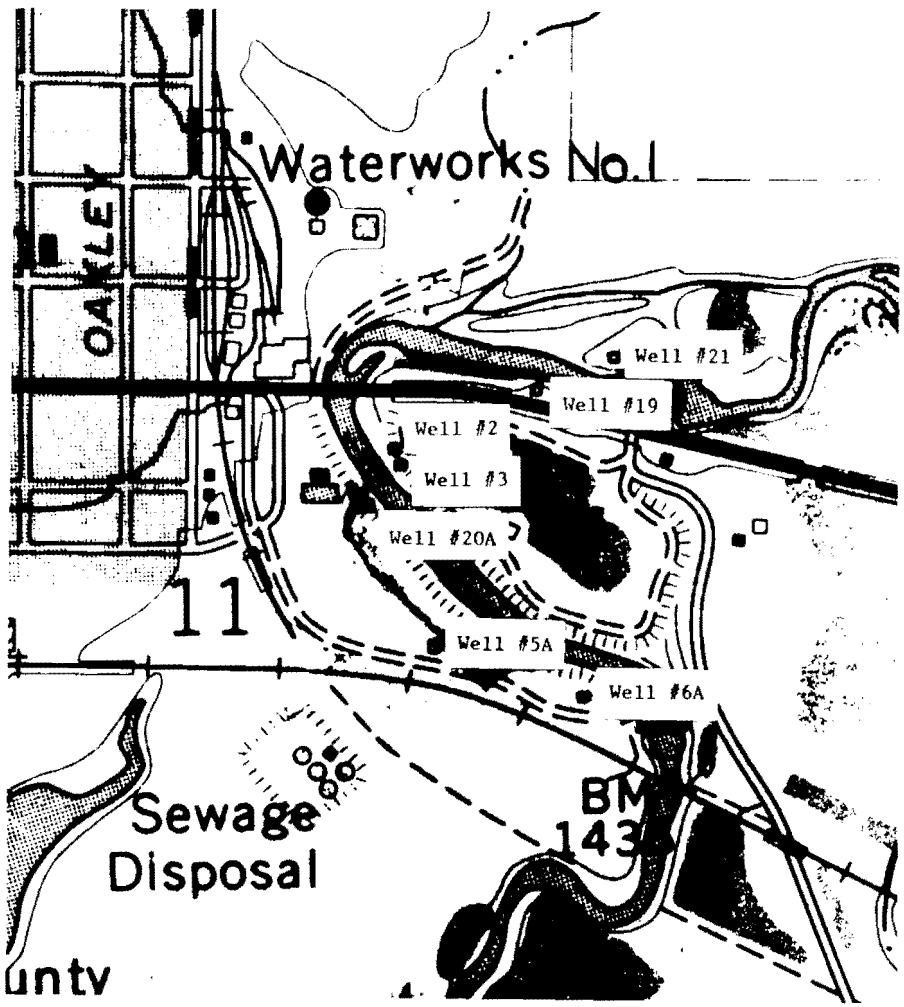


Fig. 18. Luverne, location of wells and water works No. 1, north field

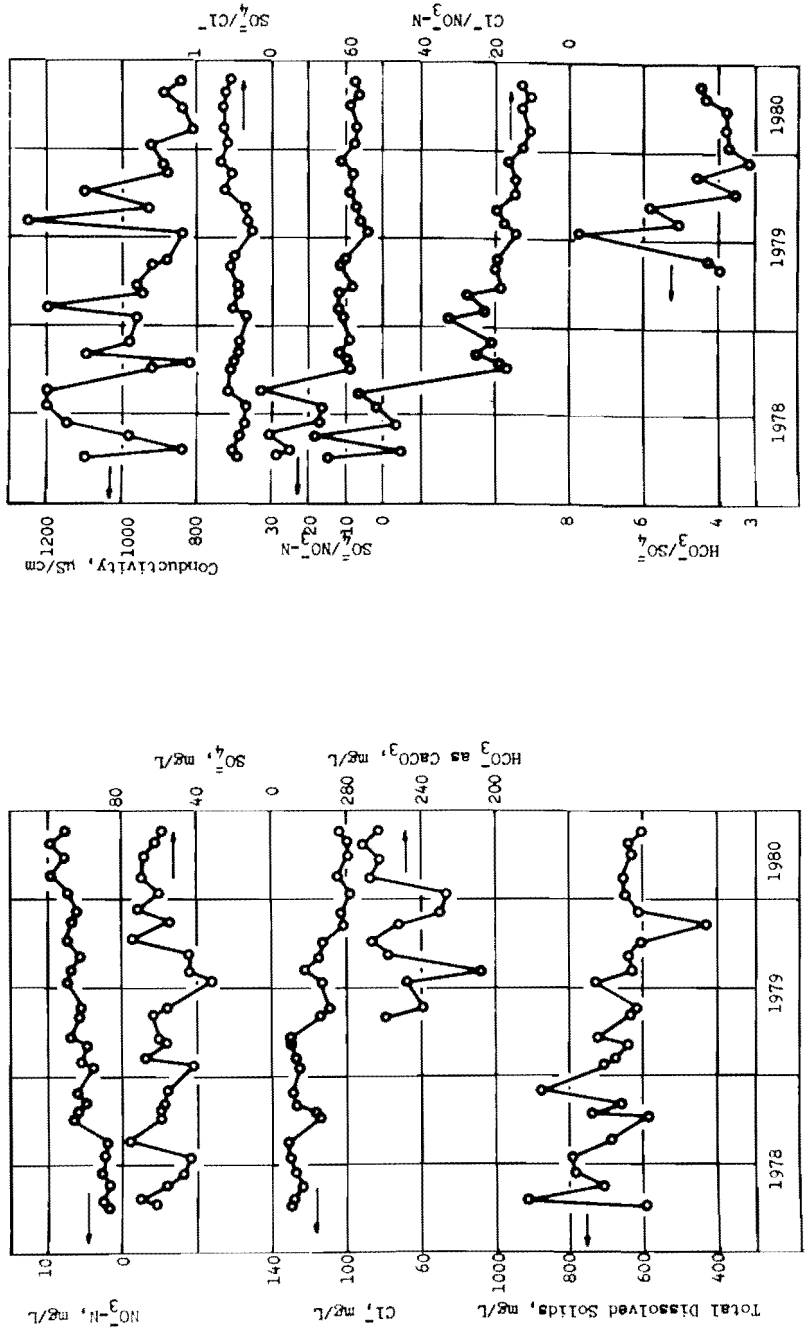


Fig. 19. Luverne, south field, well 7, analytical results

sulfate, 3.2 to 7.8, with mean and median values of 4.5 and 4.3, respectively.

7.2.1.2. Well 9

Well 9 results are plotted in Fig. 20 and are summarized as follows: sulfate ranged from 45 to 120 mg/L, with mean and median values of 80 and 82 mg/L, respectively; chloride, 120 to 160 mg/L, with mean and median values of 150 mg/L; nitrate-nitrogen, 0 to 0.80 mg/L, with mean and median values of <0.20 and <0.10, mg/L, respectively; bicarbonate, 230 to 280 mg/L, with mean and median values of 260 mg/L; total dissolved solids, 810 to 1300 mg/L, with mean and median values of 730 and 750 mg/L, respectively; conductivity, 870 to 1300 µS/cm, with mean and median values of 1100 µS/cm; and pH, 7.1 to 8.0, with mean and median value of 7.5. Calculated ratios were: sulfate/chloride, 0.31 to 0.97, with mean and median values of 0.55 and 0.56, respectively; sulfate/nitrate-nitrogen, 95 to infinity, with mean and median values of >690 and 680, respectively; chloride/nitrate-nitrogen, 180 to infinity, with mean and median values of >1200 and 1500, respectively; and bicarbonate/sulfate, 2.4 to 4.1, with mean and median values of 3.0.

7.2.1.3. Well 10

Results for Well 10 are plotted in Fig. 21 and are summarized below. Sulfate concentrations ranged from 30 to 120 mg/L, with mean and median values of 54 and 49 mg/L, respectively; chloride, 76 to 140 mg/L, with a mean and median value of 120 mg/L; nitrate-nitrogen, 3.5 to 17 mg/L, with a mean and median value of 8.7 and 9.5, respectively; bicarbonate alkalinity, 230 to 280 mg/L, with mean and median values of 260 and 270 mg/L, respectively; total dissolved solids, 230 to 800 mg/L, with a mean and median value of 640 and 670 mg/L, respectively; conductivity, 800 to 1200 µS/cm, with mean and median values of 1000 to 990 µS/cm, respectively; and pH, 7.0 to 7.8, with a median value of 7.6. Calculated ratios were: sulfate/chloride, 0.27 to 0.92, with a mean and median value of 0.46 and 0.41, respectively; sulfate/nitrate-nitrogen, 2.8 to 22, with mean and median values of 7.5 to 5.2, respectively; chloride/nitrate-nitrogen, 7.3 to 39, with mean and median values of 16 to 12, respectively, and bicarbonate/sulfate, 5.4 to 8.4, with mean and median values of 6.8 and 6.6, respectively.

7.2.1.4. Well 12

The results for Well 12 are plotted in Fig. 22 and are summarized below. Sulfate concentrations ranged from 22 to 100 mg/L, with mean and median values of 59 and 58 mg/L, respectively; chloride, 120 to 170 mg/L, with mean and median values of 140 mg/L; nitrate-nitrogen, 4.4 to 16 mg/L, with mean and median values of 9.8 and 10 mg/L, respectively; bicarbonate alkalinity, 220 to 320 mg/L, with a mean and median value of 280 mg/L; total dissolved solids, 420 to 860 mg/L, with mean and median values of 720 and 740 mg/L, respectively; conductivity, 810 to 1300 µS/cm, with mean and median values of 1100 and 1200 µS/cm, respectively; and pH, 7.3 to 7.8, with a median value of 7.6. Calculated ratios were: sulfate/chloride ranged from 0.14 to 0.83, with mean and median values of 0.42; sulfate/nitrate-nitrogen, 1.9 to 18, with mean and median values of 7.0 and 6.0, respectively; chloride/nitrate-nitrogen, 9.5 to 34, with mean and median values of 16 to 14, respectively; and bicarbonate/sulfate, 3.2 to 14, with mean and median

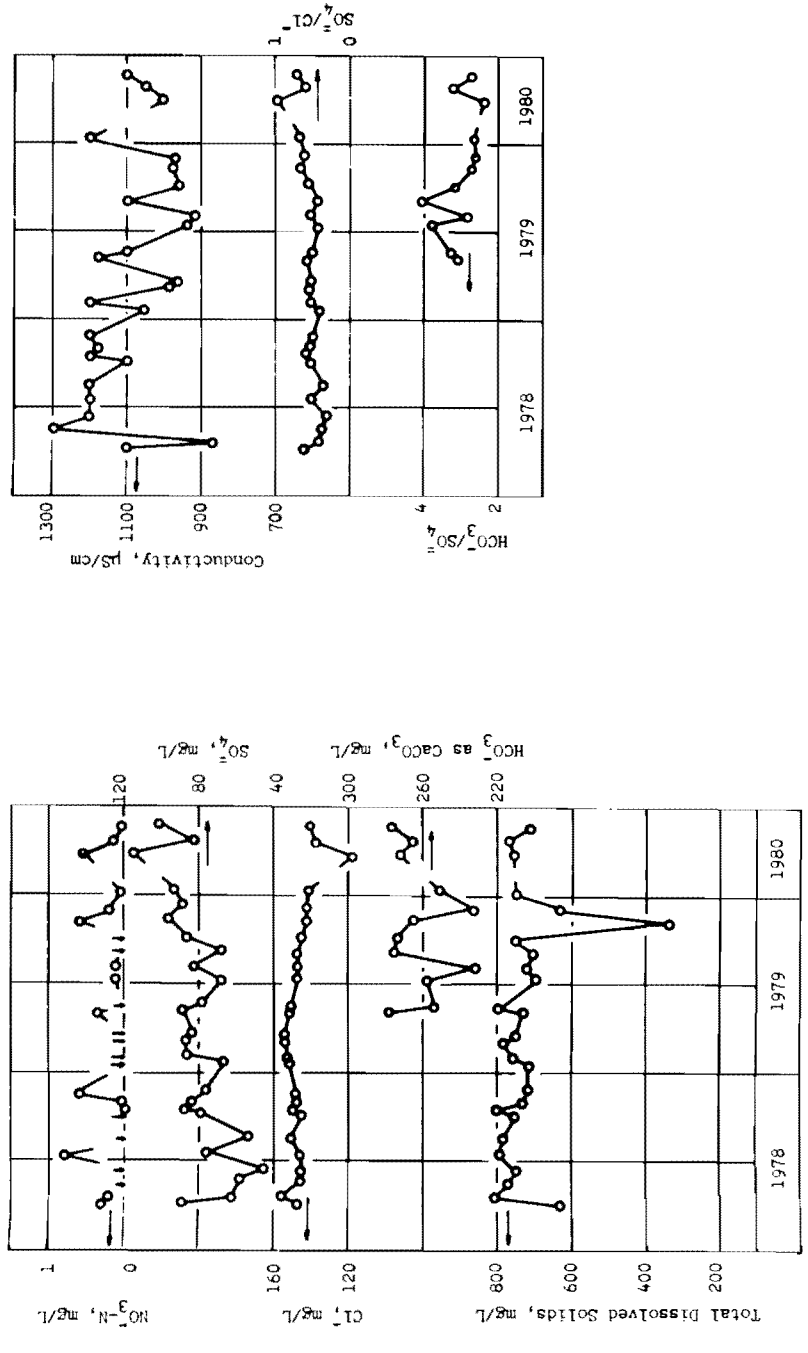


Fig. 20. Laverne, south field, well 9, analytical results

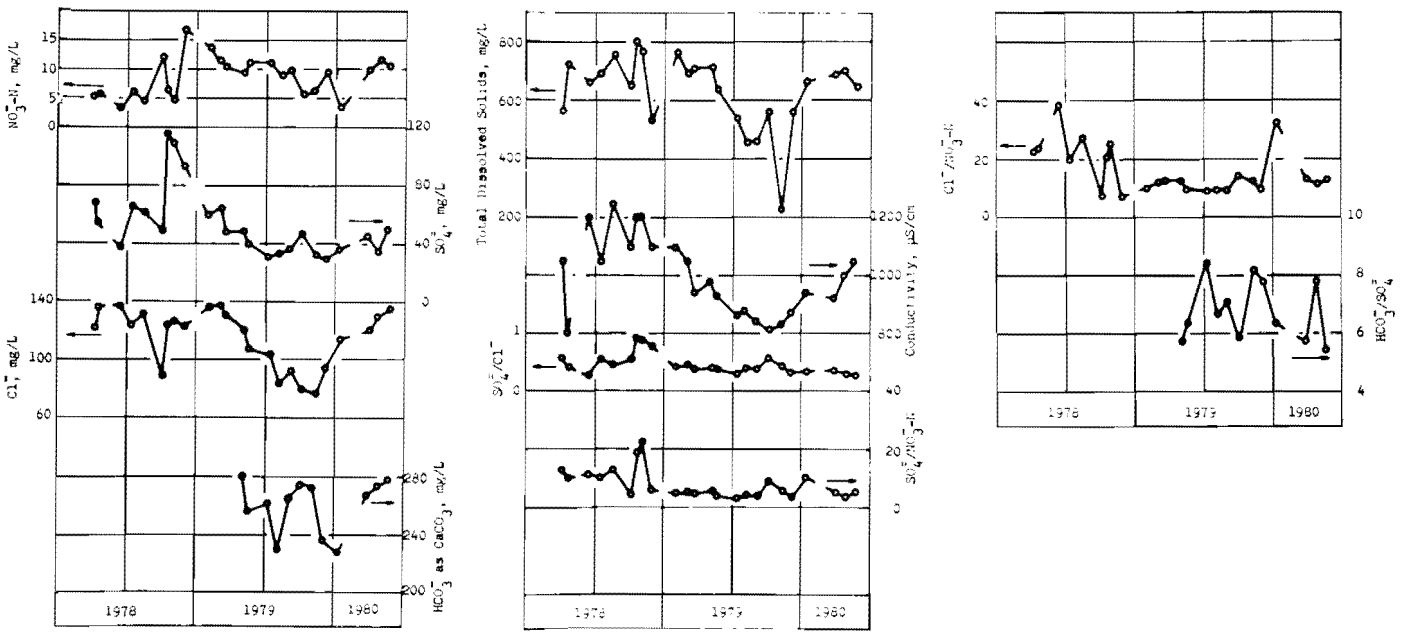


Fig. 21. Luverne, south field, well 10, analytical results

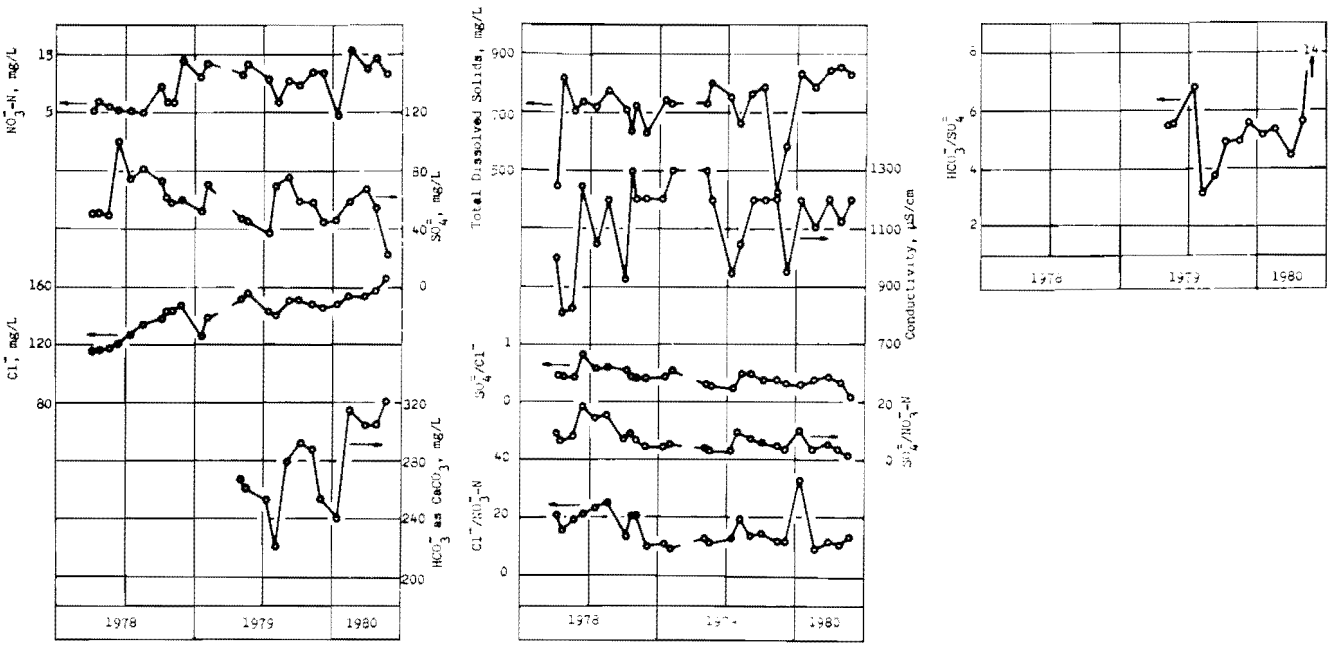


Fig. 22. Luverne, south field, well 12, analytical results

values of 5.8 and 5.4, respectively.

7.2.1.5. Well 12B

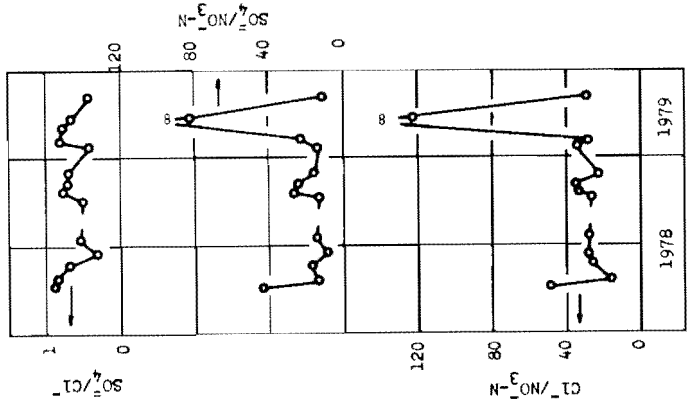
The results plotted in Fig. 23 are based on 14 samples, because the pump went out and was not replaced. These results are summarized as follows: sulfate concentrations ranged from 35 to 100 mg/L, with mean and median values of 83 and 91 mg/L, respectively; chloride, 110 to 160 mg/L, with a mean and median value of 130 mg/L; nitrate-nitrogen, 0 to 6.8 mg/L, with mean and median values of 4.0 and 4.2 mg/L, respectively; bicarbonate alkalinity, one value at 300 mg/L; total dissolved solids, 540 to 800 mg/L, with mean and median values of 690 and 710 mg/L, respectively; conductivity, 770 to 1300 µS/cm, with mean and median values of 1100 and 1000 µS/cm, respectively; and pH, one value at 7.5. Calculated ratios were: sulfate/chloride, range 0.31 to 0.89, with mean and median values of 0.65 and 0.70, respectively; sulfate/nitrate-nitrogen, range 9.0 to infinity, with mean and median values of >28 and 17, respectively; chloride/nitrate-nitrogen, range 16 to infinity, with mean and median values of >43 and 29, respectively; and bicarbonate/sulfate, one value at 4.6.

7.2.1.6. Well 11

The results for Well 11 are plotted in Fig. 24 and are summarized below. Sulfate concentrations ranged from 74 to 220 mg/L, with mean and median values of 180 mg/L; chloride, 100 to 120, mg/L, with a mean and median value of 110 mg/L; nitrate-nitrogen, 0 to 0.34 mg/L, with a mean and median value of 0.12 and 0.10 mg/L, respectively; bicarbonate alkalinity, 200 to 280 mg/L, with mean and median values of 260 and 280 mg/L, respectively; total dissolved solids, 520 to 970 mg/L, with mean and median values of 780 and 810 mg/L, respectively; conductivity, 840 to 1300 µS/cm, with mean and median values of 1000 and 1200 µS/cm, respectively; and pH, 7.3 to 8.0, with a median value of 7.6. Calculated ratios were: sulfate/chloride range 0.67 to 2.2, with mean and median values of 1.7 and 1.6, sulfate/nitrate-nitrogen, 220 to infinity, with mean and median values of >1500 and 1600, respectively; chloride/nitrate-nitrogen, 330 to infinity, with mean and median values >1100 and 1000, respectively; and bicarbonate/sulfate, 1.1 to 2.7, with mean and median values of 1.5 and 1.4, respectively.

7.2.1.7. Well 13

The results for Well 13 are plotted in Fig. 25 and are summarized as follows: sulfate concentrations ranged from 52 to 130 mg/L, with mean and median values of 92 and 96 mg/L, respectively; chloride, 100 to 270 mg/L, with mean and median concentrations of 140 and 120 mg/L, respectively; nitrate-nitrogen, 0 to 11 mg/L, with mean and median values of 1.2 and 0.20 mg/L, respectively; bicarbonate alkalinity, 120 to 330 mg/L, with mean and median values of 240 and 260 mg/L, respectively; total dissolved solids, 480 to 1000 mg/L, with mean and median values of 720 and 730 mg/L, respectively; conductivity, 810 to 1400 µS/cm, with mean and median values of 1100 and 1000 µS/cm, respectively; and pH, 7.3 to 7.8, with a median value of 7.5. Calculated ratios were: sulfate/chloride, range 0.25 to 1.3 with mean and median values of 0.73 and 0.74, respectively; sulfate/nitrate-nitrogen, 5.4 to infinity, with mean and median values of >520 and 650, respectively; chloride/nitrate-nitrogen, 20 to infinity, with mean and median values of >710 and 510, respectively; and bicarbonate/sulfate, 1.4



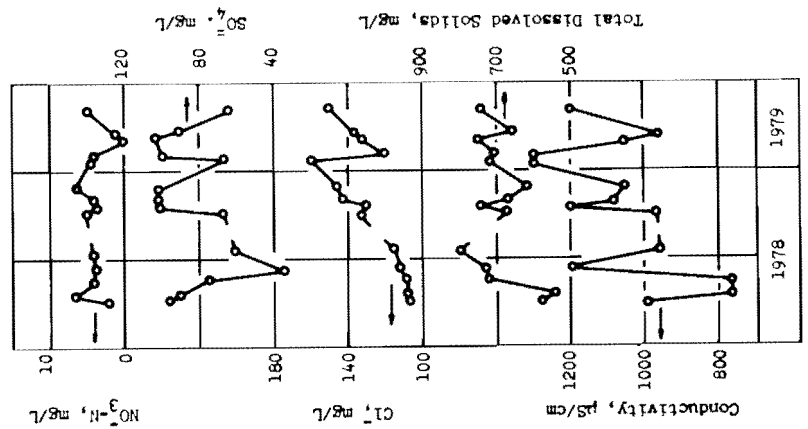


Fig. 23. Luverne, south field, well 12B, analytical results

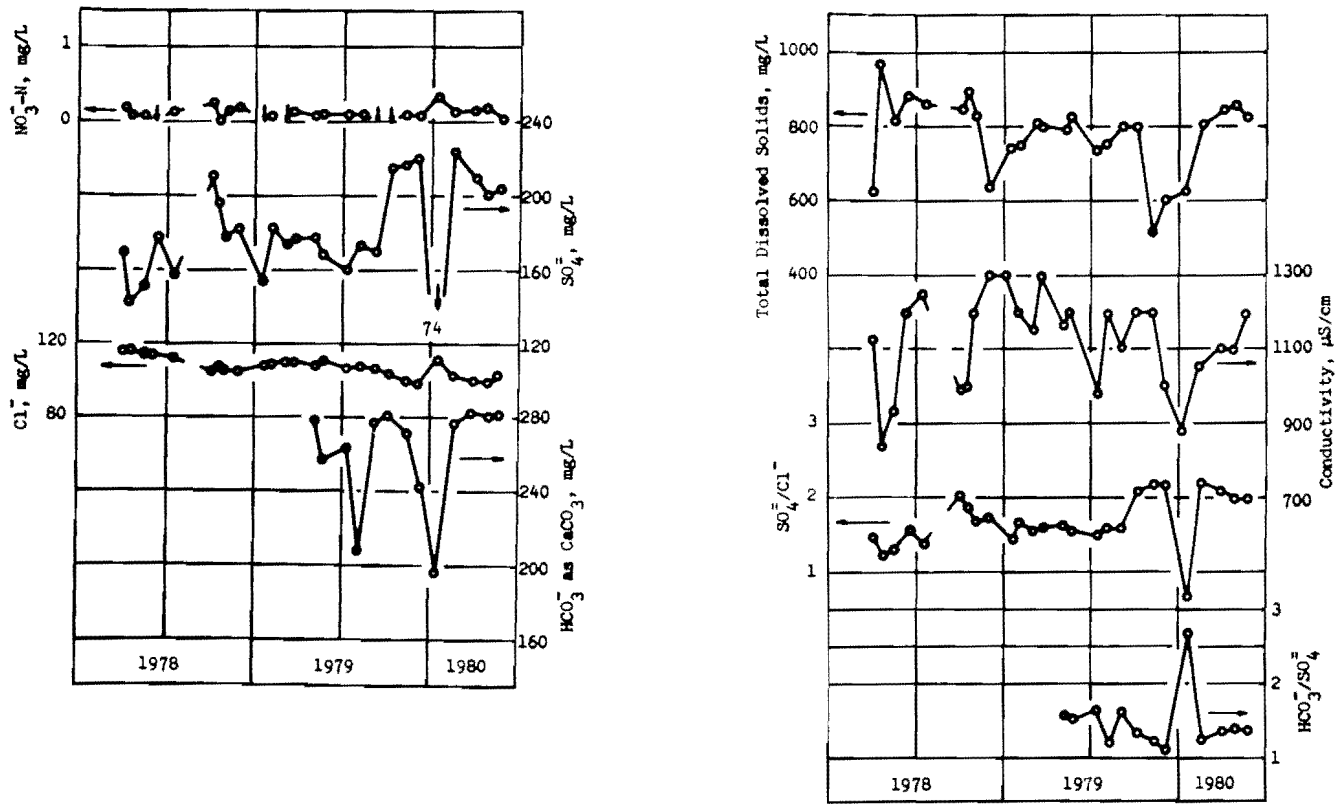


Fig. 24. Luverne, south field, well 11, analytical results

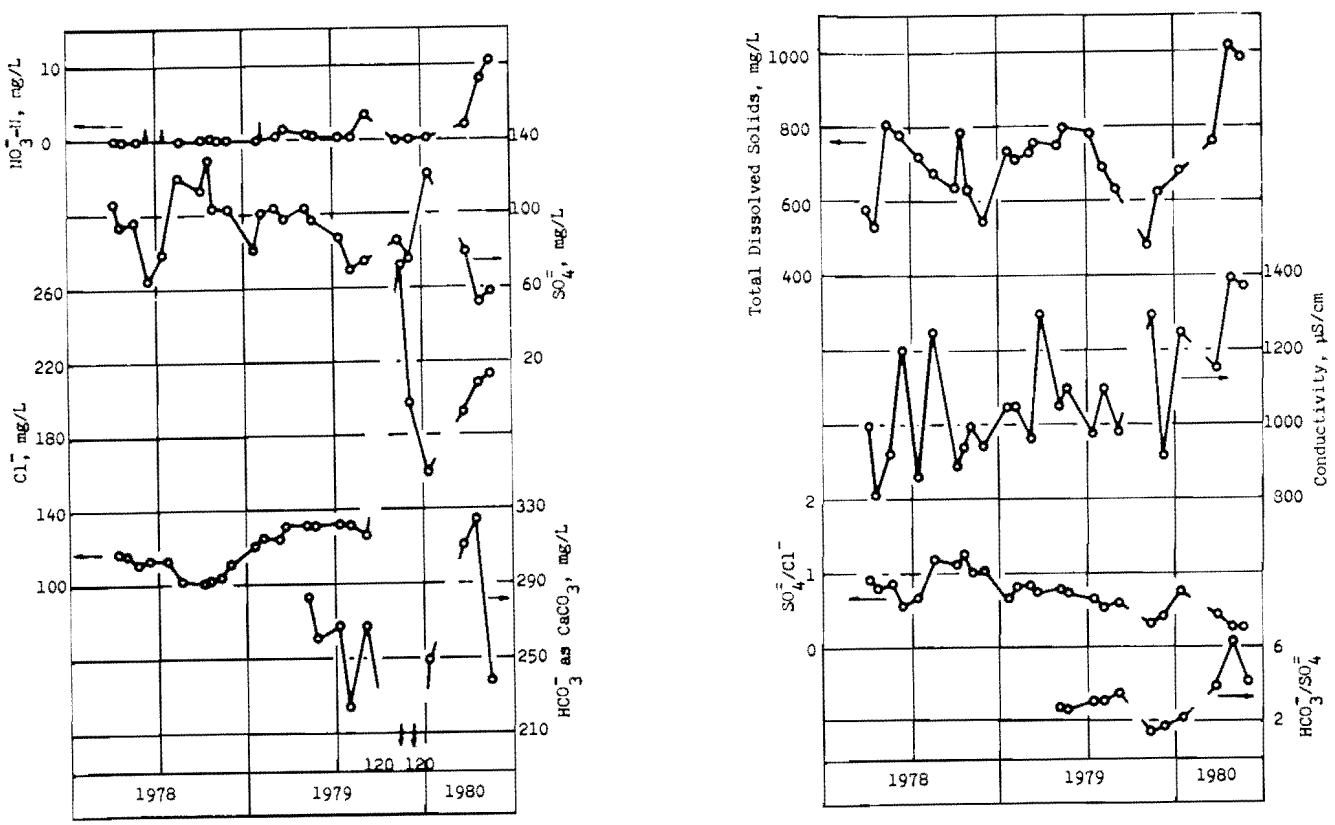


Fig. 25. Luverne, south field, well 13, analytical results

to 6.3, with mean and median values of 3.2 and 3.1, respectively.

7.2.1.8. Waterworks No. 2

The integrated input from the preceding wells into Waterworks 2 are plotted in Fig. 26 and are summarized as follows: sulfate concentrations ranged from 50 to 150 mg/L, with mean and median values of 99 to 100 mg/L, respectively; chloride, 110 to 190 mg/L, with mean and median values of 130 mg/L; nitrate-nitrogen, 1.7 to 7.0 mg/L, with mean and median values of 4.4 and 4.6 mg/L, respectively; bicarbonate alkalinity, 230 to 280 mg/L, with mean and median values of 260 and 270 mg/L, respectively; total dissolved solids, 540 to 850 mg/L, with mean and median values of 740 mg/L; conductivity, 890 to 1400 µS/cm, with a mean and median value of 1100 µS/cm, respectively; and pH, 7.4 to 8.2, with a median value of 7.7. Calculated ratios were: sulfate/chloride range 0.40 to 1.4, with a mean and median value of 0.78; sulfate/nitrate-nitrogen, 11 to 42, with a mean and median value of 24; chloride/nitrate-nitrogen, 19 to 76, with a mean and median value of 33 and 28, respectively; and bicarbonate/sulfate, 1.8 to 5.2, with mean and median values of 2.8 and 2.7, respectively.

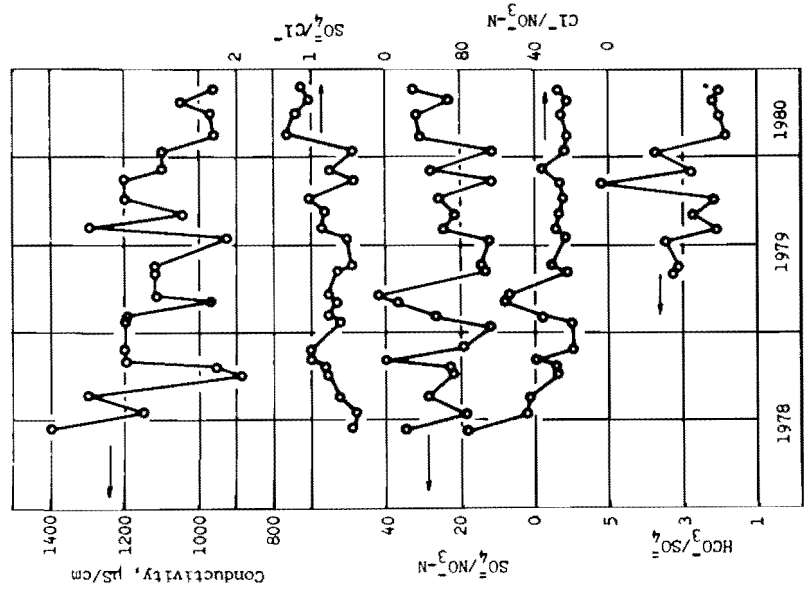
7.2.2. North Field

7.2.2.1. Wells 2, 3, 5A, 6A, 20A, 19, and 21

Because the variation in these wells was not influenced appreciably by land use practices or location, being in a park or nearby area, the results are summarized collectively. The results of Well 19 are not included. Sulfate concentrations ranged from 48 to 160 mg/L, with mean and median ranges of 85 to 100 and 84 to 100 mg/L, respectively; chloride, 11 to 75 mg/L, with mean and median ranges of 18 to 50 and 17 to 46 mg/L, respectively; nitrate-nitrogen, 0 to 1.6 mg/L, with mean and median ranges of <0.09 to <0.27 and <0.10 to 0.14, respectively; bicarbonate alkalinity, 190 to 320 mg/L, with mean and median ranges of 250 to 280 and 250 to 300 mg/L, respectively; total dissolved solids, 140 to 720 mg/L, with mean and median ranges of 450 to 530 and 460 to 540 mg/L, respectively; conductivity, 420 to 930 µS/cm, with mean and median ranges of 690 to 830 and 680 to 800 µS/cm, respectively; and pH, 7.2 to 8.4, with a median range of 7.5 to 7.8. Calculated ratios are reported for sulfate/chloride and bicarbonate/sulfate, since with the low nitrate-nitrogen values observed, the sulfate/nitrate-nitrogen and chloride nitrate-nitrogen values are not very meaningful. Sulfate/chloride ratios ranged from 0.14 to 8.1 with mean and median ranges of 2.0 to 5.1 and 1.8 to 5.1, respectively; and bicarbonate/sulfate, range 2.0 to 5.0, with mean and median ranges of 2.6 to 3.3.

7.2.3. Waterworks No. 1

The results observed for Waterworks No. 1, which received waters from Wells 2, 3, 5A, 6A, 20A, and 21, are plotted in Fig. 27, and are summarized as follows: sulfate concentrations ranged from 74 to 210 mg/L, with a mean and median value of 110 mg/L; chloride, 17 to 53, with a mean and median value of 38 mg/L; nitrate-nitrogen, 0 to 1.6 mg/L, with mean and median values of <0.24 and <0.10 mg/L, respectively; bicarbonate alkalinity, 180 to 270 mg/L, with a mean and median value of 220 mg/L; total dissolved solids, 330 to 550 mg/L, with a mean and median value of 460 mg/L; conductivity, 650 to 820 µS/cm, with mean and median values of 720 and 710



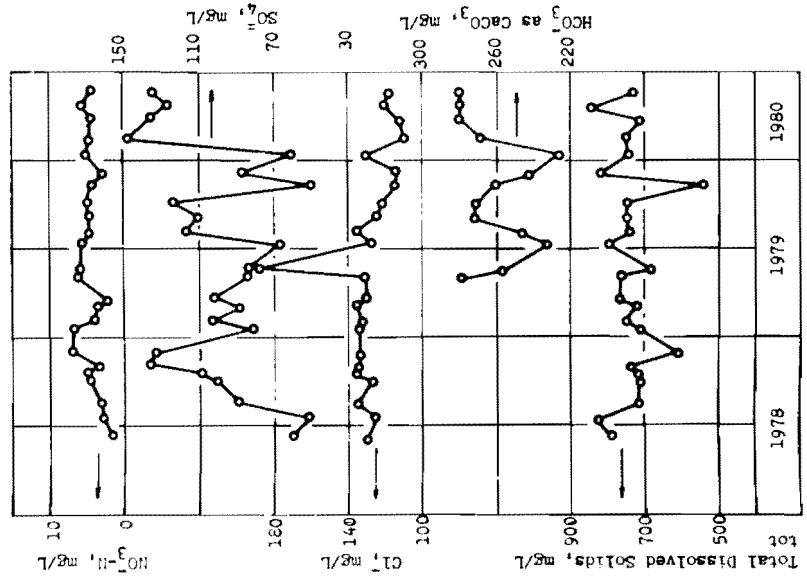


Fig. 26. Iuverne, south field, water works No. 2, analytical results

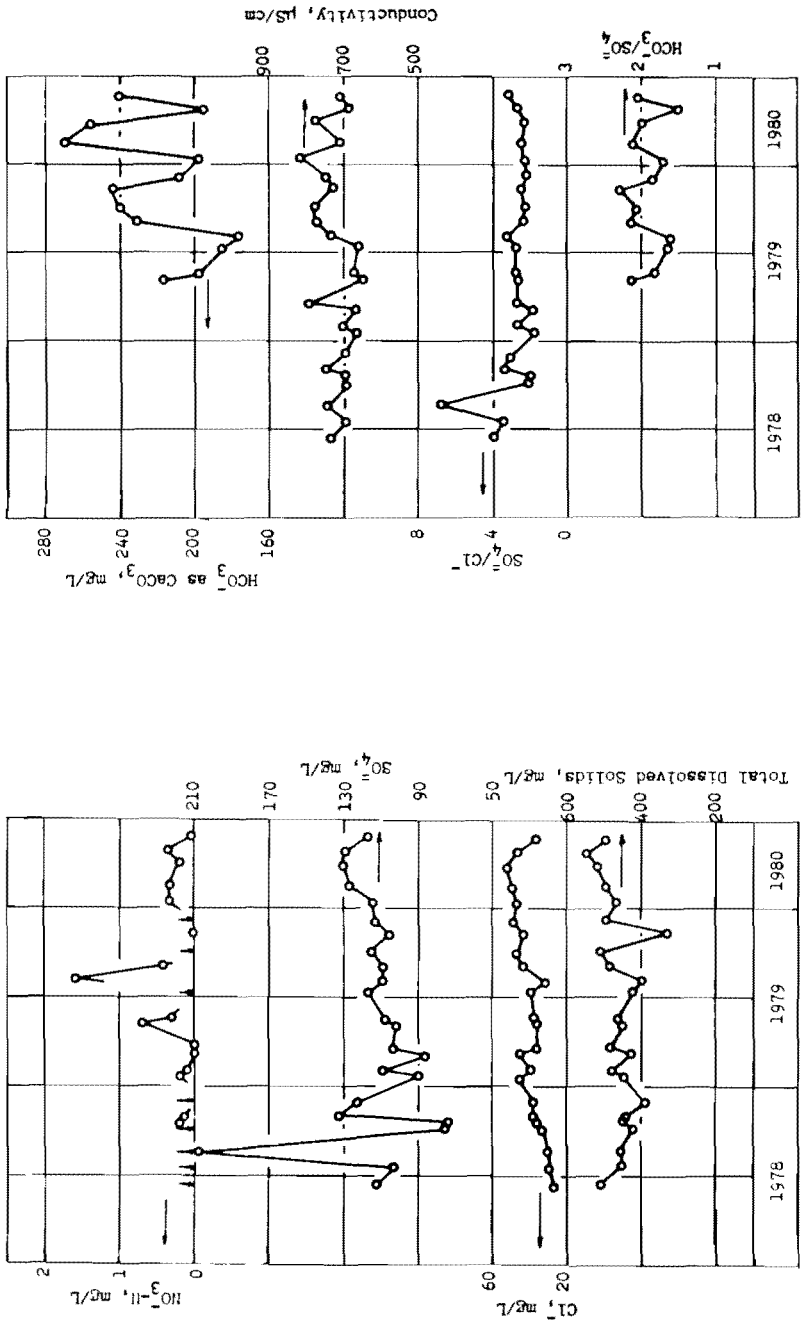


Fig. 27. Luverne, north field, water works No. 1, analytical results

µS/cm, respectively; and pH, 7.2 to 8.4, with mean and median value of 7.9. Calculated ratios were: sulfate/chloride, range 1.9 to 6.9, with mean and median values of 2.9 and 2.8, respectively; and bicarbonate/sulfate, 1.5 to 2.3, with mean and median values of 1.9 and 2.0, respectively. Values for sulfate/nitrate-nitrogen and chloride/nitrate-nitrogen are not given because the nitrate-nitrogen values were low or equalled zero.

7.2.4. Distribution System

The results for the distributions system samples, a composite of contributions from Waterworks No. 1 and No. 2, are plotted in Fig. 28, and are summarized as follows: sulfate concentrations ranged from 61 to 150 mg/L, with mean and median values of 100 mg/L; chloride, 38 to 140 mg/L, with mean and median values of 84 to 83 mg/L, respectively; nitrate-nitrogen, 0 to 6.0 mg/L, with mean and median values of 2.4 and 2.0 mg/L, respectively; bicarbonate alkalinity, 200 to 300 mg/L, with a mean and median value of 250 mg/L; total dissolved solids, 240 to 780 mg/L, with mean and median values of 580 and 560 mg/L, respectively; conductivity, 680 to 1100 µS/cm, with mean and median values of 890 and 850 µS/cm, respectively; and pH, 7.0 to 8.2, with a median value of 7.8. Sulfate/chloride ratios ranged from 0.61 to 3.0, with mean and median values of 1.4 and 1.3, respectively, and bicarbonate/sulfate ratios ranged from 1.5 to 3.3, with mean and median values of 2.4. Median sulfate/nitrate-nitrogen and chloride/nitrate-nitrogen values were 46 to 49, respectively.

7.3. Discussion

7.3.1. South Field

Earlier findings have been reported,[11] and generally show no large change in the concentrations of the constituents measured, except for chloride. Wells 7, 9, 10, 11, 12, and 13 all showed marked increases in chlorides. The source of this chloride is not readily identifiable at this time.

There is a direct relation between nitrate-nitrogen levels in the various wells and land use. Higher levels of ntirate-nitrogen occurred in those wells in closest proximity or within agricultural activities.

7.3.2. North Field

Only Wells 2 and 3 had previous values[11] that could be compared with our findings. In general, all values were within ranges which we reported.

7.3.3. Distribution System

A single sample collected in October 1968[11] from the distribution system had values similar to our values with the exception of chloride, which was lower than the values we reported.

7.4. Conclusions

The following conclusions may be drawn from the results reported.

1. Nitrate-nitrogen concentrations are highest in those wells located in actively farmed areas.

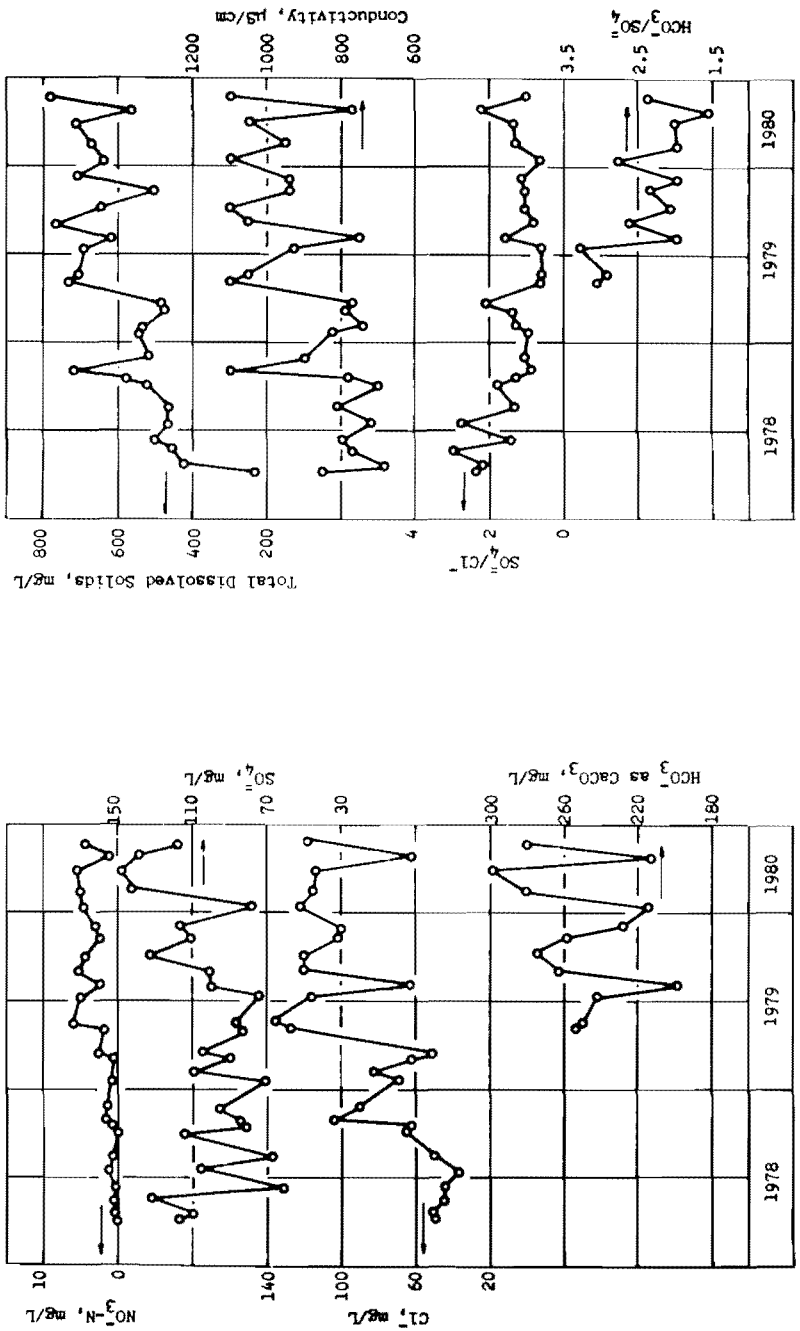


Fig. 28. Luverne, distribution system, analytical results

2. Over the past 10 years or more, there has been a marked increase in the chloride concentration in all wells in the south field.

3. No appreciable changes have been observed in the quality of water taken from wells located in the north field.

4. Blending of lesser quality water from the south field with the higher quality water from the north field produces a more satisfactory water for consumer use. Almost all samples collected from wells in the south field exceeded the total dissolved solids secondary recommended level of 500 mg/L, and fewer samples from wells in the north field exceeded this level. Of the 27 samples collected from the distribution system 20 exceeded 500 mg/L.

8.0. INDIVIDUAL FARM WELL

8.1. Introduction

To provide a comparison between an individual private water supply and the quality of water served by a municipal system, and individual farm located along the banks of the Rock River near Hardwick was sampled. The supply consisted of a shallow well located in an area between farm buildings used to house various farm animals and the River. The area in the vicinity of the well was used also as a pen area for some of the animals.

The sampling point was located in what was formerly the milk house. Initial samples were taken in a channel where a tap was located, but when this area was converted to hog raising, the sampling point was moved to a tap in an adjoining building to the milk house.

8.2. Results

The results obatined are plotted in Fig. 29 and are summarized as follows: sulfate concentrations ranged from 130 to 330 mg/L, with mean and median values of 230 and 240 mg/L, respectively; chloride, 140 to 280 mg/L, with mean and median values of 200 and 190 mg/L, respectively; nitrate-nitrogen, 9.1 to 33 mg/L, with mean and median values of 16 and 14 mg/L, respectively; bicarbonate alkalinity, 470 to 690 mg/L, with mean and median values of 570 to 540 mg/L, respectively; total dissolved solids, 1100 to 2000 mg/L, with a mean and median value of 1500 mg/L; conductivity, 1600 to 2800 µS/cm, with a mean and median value of 2200 µS/cm; and pH, 7.1 to 7.9, with a median value of 7.2. Calculated ratios were; sulfate/chloride, 0.67 to 1.6, with mean and median values of 1.2 and 1.1, respectively; sulfate/nitrate-nitrogen, 7.0 to 27, with a mean and median value of 15; chloride/nitrate-nitrogen, 6.7 to 22, with mean and median values of 14 and 13, respectively; and bicarbonate/sulfate, 1.6 to 3.1, with a mean and median value of 2.2.

8.3. Discussion

The concentration reported above are all higher than those observed in wells serving as sources of municipal water supply, except for nitrate-nitrogen values reported in Well 2, Adrian.

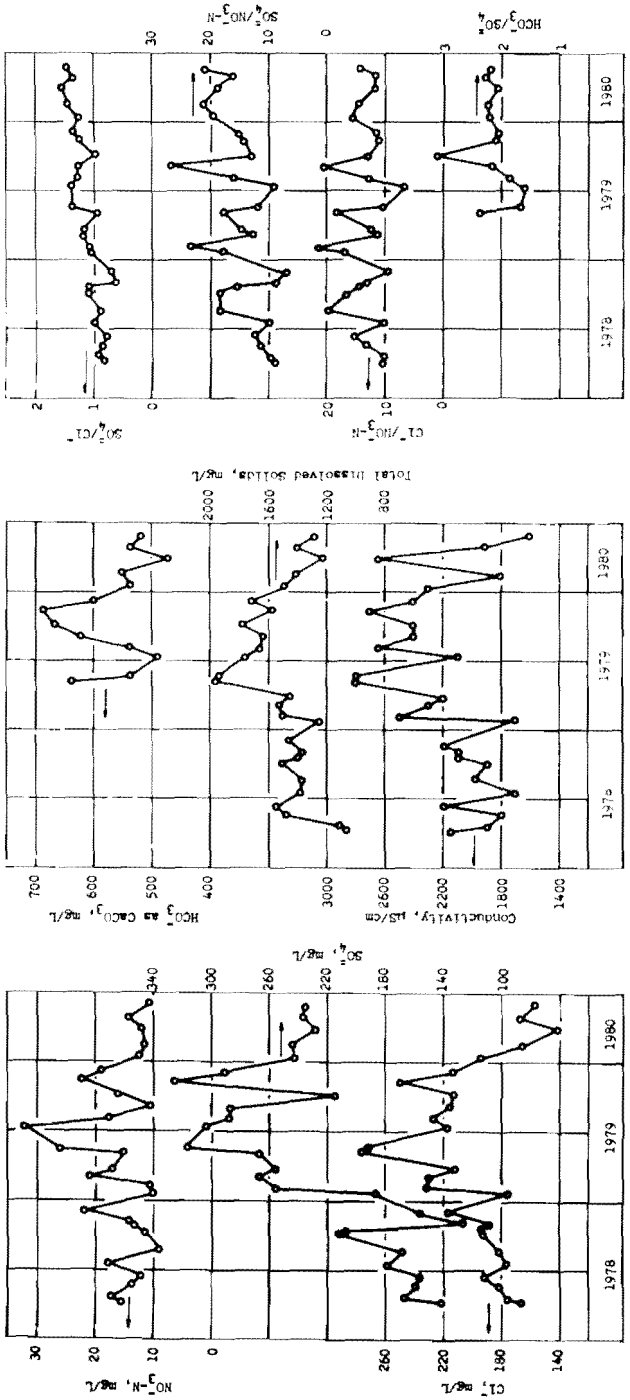


Fig. 29. Individual farm well, analytical results

In reviewing our findings with the rural family using the supply, we were informed that because of the deterioration which had been taking place in water quality, and problems associated with use of water by young farm animals, the family opted to obtain its water from a Rural Water District serving the area.

8.4. Conclusions

The following conclusions are warranted.

1. Water quality in this individual rural farm well was poorer than that observed in all wells serving rural municipalities.

2. Nitrate-nitrogen concentrations exceed the permissible concentrations of 10 mg/L in 26/27 samples, sulfate in excess of 250 mg/L in 10/27 samples, chloride in excess of 250 mg/L in 2/27 samples, and total dissolved solids in excess of 500 mg/L in 27/27 samples.

3. If this well is representative of rural farm water supplies in general, it is obvious that these supplies are of unsatisfactory quality based upon the parameters measured.

9.0. REFERENCES

1. Straub, C.P., Goppers, V.M., and DuChene, A. Water Quality and Trends in Minnesota -- Indices for Water Supply and Ground Water Pollution. WRRC Bulletin 95, Water Resources Research Center, Graduate School, University of Minnesota, Minneapolis, MN (August 1977).

2. U.S. Department of Health, Education, and Welfare. Public Health Service, Public Health Service Drinking Water Standards. Revised 1962. Washington, D.C. (1962).

3. Bean, E.L., Chairman. Qaulity Goals for Potable Water -- Statement of Policy. American Water Works Assn., Task Group 2640 P. Water Quality Goals. Jour. Am. Water Works Assn., 60 (12): 1317-1322 (1968).

4. U.S. Environmental Protection Agency, Water Program: National Interim Primary Drinking Water Regulations, Federal Register, 40 (248): 59566-59588 (Dec. 24, 1975).

5. Straub, C.P., Goppers, V.M., and Singer, R.D. Water Quality Study -- Southwest Minnesota, School of Public Health, Water Resources Research Center, Graduate School, University of Minnesota, Minneapolis, MN (March 1981).

6. Anderson, H.S., Jr., Broussard, W.L., Farrell, D.F., and Felsheim, P.E. Water Resources of the Rock River Watershed, Southwestern Minnesota. Hydraulic Investigations, Atlas HA-555, Published by the U.S. Geological Survey, Reston, VA (1976).

7. Kuehnast, E.L. Personal communication. (1981).

8. Domagele, D. Personal communication. (1980).

9. Standard Methods for the Examination of Water and Wastewater, 14th Edition. APHA, AWWA, WPCF, American Public Health Assn., Washington, D.C. (1975).

10. U.S. Environmental Protection Agency. National Secondary Drinking Water Regulations, Federal Register, 42 (62): 17143-17147 (March 31, 1977).

11. Minnesota Department of Health, Division of Environmental Health. State of Minnesota -- Public Water Supply Data -- 1977

Prepared - September 1982